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Demonstration of Cathodic Protection Systems for Utilities in Severely Corrosive Environments at Fort Jackson

Final Report on Project FAR-20 for FY06

L.D. Stephenson, Ashok Kumar, James B. Bushman,
and Bopinder Phull

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Demonstration of Cathodic Protection Systems for Utilities in Severely Corrosive Environments at Fort Jackson

Final Report on Project FAR-20 for FY06

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Final report

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Abstract: This project demonstrated and implemented emerging corrosion protection technologies for utilities at Fort Jackson, SC. These consisted of three deep anode impressed current cathodic protection (ICCP) systems, 100 drive-by-type remote monitoring units (RMU) for monitoring the cathodic protection on the buried gas lines, and a new cathodic protection system in the elevated water storage tank, providing complete and uniform protection in the tank interior below the water line. The CP system in the water storage tank is also equipped with remote monitoring capability. The remote monitoring units have reduced the amount of time that it takes a trained technician to collect the data from about a week to only about 3 hours. The CP data collected from the drive by RMUs are collected and stored on a laptop computer for use in different analysis, including transfer into an Excel spreadsheet where it is automatically analyzed on a pass/fail basis.

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Preface

This demonstration was performed for the Office of the Secretary of Defense (OSD) under Department of Defense (DoD) Corrosion Control and Prevention Project FAR-20, “Cathodic Protection Systems for Utilities in Severely Corrosive Environments”. The proponent was the U.S. Army Office of the Assistant Chief of Staff for Installation Management (ACSIM), and the stakeholder was the U.S. Army Installation Management Command (IMCOM). The technical monitors were Daniel J. Dunmire (OUSD(AT&L)Corrosion), Paul M. Volkman (IMPW-E), and David N. Purcell (DAIM-FDF).

The work was performed by the Engineering and Materials Branch (CEERD-CF-M), Facilities Division (CF), U. S. Army Engineer Research and Development Center—Construction Engineering Research Laboratory (ERDC-CERL), Champaign, IL. The ERDC-CERL project managers were Dr. Ashok Kumar and Dr. L.D. Stephenson. Significant portions of this work were performed by Mr. James Bushman and Dr. Bopinder Phull of Bushman & Associates, Inc., Medina, OH. The contributions of subcontractors Loresco, Inc. of Hattiesburg, MS, Clearwater Drilling Company of Columbia, SC, and Freeman Industries of Dorset, OH are also acknowledged.

The Fort Jackson DPW personnel are gratefully acknowledged for their support and assistance in this project, especially Mr. Georges Dib, Electrical Engineer/Energy Manager, with the DPW.

At the time this report was prepared, the Chief of the ERDC-CERL Materials and Structures Branch was Vicki L. Van Blaricum (CEERD-CF-M), the Chief of the Facilities Division was L. Michael Golish, (CEERD-CF), and the Technical Director for Installations was Martin J. Savoie (CEERD-CV-ZT). The Deputy Director of ERDC-CERL was Dr. Kirankumar Topurdurti and the Director was Dr. Ilker Adiguzel.

The Commander and Executive Director of the U.S. Army Engineer Research and Development Center was COL Richard B. Jenkins and the Director was Dr. James R. Houston.

Executive Summary

This OSD Corrosion Prevention and Control project demonstrated the use of new tubular ceramic anodes that can be placed 200 ft deep in the ground. Their design makes them more water resistant than previous designs. These deep well impressed current ceramic anode beds help to more widely distribute the protection current from the ceramic anodes to protect pipelines. Three deep well anodes were placed at Fort Jackson which has a severely corrosive environment year round. 100 drive by type remote monitoring units were also installed facilitating cathodic protection data to be collected in three hours that previously took a week to collect. This data is automatically downloaded into a software program which allows the installation to quickly determine if the cathodic protection is working at each of those sites. All measurement parameters including time between data samples, length of time period during which instant off potential's are measured and time period over which polarization decay is assessed are all user selectable values. Thus the system can also be utilized on other pipe materials such as ductile iron, aluminum and copper which have different criteria for cathodic protection than that used on buried steel pipe.

A new ceramic mixed metal oxide anode system was installed in the 2 million gallon elevated water storage tank replacing a failing silicon –iron anode system. The new anode material connections are made above the high water line preventing the ingress of water into the connection and subsequent failure of the anode material. The anode life of the new ceramic wire anode material is conservatively calculated at greater than 40 years in this particular water storage tank. Data collected through the remote monitoring drive by system that was also installed, indicates that the tank is now receiving complete and uniform cathodic protection in the tank interior below the waterline.

Recommendations will be provided for revisions to Unified Facilities Guide Specifications (UFGS) -26 42 15.00 10 "Cathodic Protection System (Steel Water Tanks)" and UFGS -26 42 17.00 10 "Cathodic Protection System (Impressed Current)." These revisions include the specifications and instructions for installing the advanced impressed current cathodic protection systems in conjunction with the "drive-by" remote monitoring units for utilities as demonstrated under this project.

Unit Conversion Factors

Multiply	By	To Obtain
degrees Fahrenheit	$(F-32)/1.8$	degrees Celsius
ft	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
mils	0.0254	millimeters
square ft	0.09290304	square meters

1 Introduction

1.1 Problem statement

Fort Jackson, SC, is located in a severely corrosive environment, with highly corrosive soil and hot, humid weather. A recent corrosion protection survey there identified a lack of cathodic protection (CP) systems on underground natural gas distribution piping, which is required by law. Also, failed anodes were discovered in a 2 million gallon potable water storage tank. CP systems counteract the effects of corrosive soils on underground pipelines and the warm, humid corrosive environment inside water storage tanks.

Fort Jackson's natural gas piping system is made of coated welded steel pipe. A new CP system using tubular anodes was designed and implemented to protect the underground gas pipelines. A new CP system using mixed metal oxide (MMO) anode was designed and implemented to protect the inside of the water tank below the water line.

Providing CP systems for critical infrastructure is required to avoid utility service interruptions and safety hazards. Ensuring that CP systems provide continuous corrosion protection can be very time consuming for installation personnel, and higher-profile priorities may interfere with CP system inspections. The Office of the Secretary of Defense Corrosion Prevention and Control (CPC) Program demonstration project described here addressed both the need for purpose-designed CP systems at Fort Jackson and the need to facilitate frequent and comprehensive CP system monitoring and analysis. In that connection, the new CP systems implemented in this demonstration were outfitted with remote monitoring units (RMUs) to enable Fort Jackson personnel to monitor the performance of the new CP systems and log data from them in "drive-by" mode from a vehicle, using a standard laptop computer. The purpose of the drive by RMUs is to reduce the time and resources required to ensure that these critical CP systems are functioning properly over time.

1.2 Objective

The objective of this project was to evaluate remote corrosion monitoring needs of pipes and other utility systems, and implement a remote corrosion monitoring system at Fort Jackson.

1.3 Approach

This project entailed the following tasks:

- Install three new deep well anode CP systems with tubular anodes to protect the underground natural gas distribution pipes
- Install a new CP system to protect the elevated water storage tank.
- Install remote monitoring technology that uses a drive-by method in which CP system data can be automatically downloaded to a portable computer in a installation user friendly format that quickly identifies CP problem areas.

Similar deep anode impressed current cathodic protection systems with drive by remote monitoring units were installed at Fort Carson previously. The details and results of this work can be found in the technical report on CPC Project AR-F-321, ERDC-CERL TR-07-25 (Stephenson et al. 2007, in preparation). The Fort Carson work directly applied to how the Fort Jackson work was approached and accomplished.

Fort Jackson has a severely corrosive environment year round whereas Fort Carson's is more seasonal. The soil types vary over a depth of 1 to 5 ft, with sand at a depth of about 1 ft deep, to loam at 2 ft, to clay from 3-5 ft deep. This variation in types of soil and the constant high wetness throughout the year, due to an average annual rainfall of 50 inches creates corrosion cells at interfaces between the soil types. The deep well anode chosen for Fort Jackson was therefore chosen to withstand this harsher environment. The variation of the depth that bedrock was hit also impacted the placement of the deep well anodes.

Because of the warmer climate at Fort Jackson, the CP system designed for the water storage tank allowed the use of a new system that would be damaged if exposed to ice of more than 1–2 in. inside the tank, as happens at many installations. The new system is suspended from the roof of the tank making it easier to maintain and inspect, as it does not require draining of the tank. It is also less expensive to install.

The remote monitoring system was also upgraded to allow the user more flexibility on what systems could be monitored, how often the systems were monitored and increased distance allowed to collect the data during drive by. The output of the system was designed to allow the field to easily determine if there was a problem with the CP.

Initial surveys of existing pipes were made to establish where the most beneficial placement for the deep well anodes and remote monitoring systems would be achieved. As there were not existing accurate historical records of piping, water main layouts, etc., great care had to be taken into account before and during placement of the deep well anodes.

The appendices to this report provide supplemental information on this demonstration, as follows:

- Appendix A: Comparison of Wireless Technologies for Remote Monitoring of Cathodic Protection Systems (NACE 2007)
- Appendix B: IRT Sentinel Rectifier Manuals
- Appendix C: DART RMU Hardware Specification
- Appendix D: Baseline Native Potential Surveys
- Appendix E: Test Rectifier Data
- Appendix F: DART RMU Data.

2 Technical Investigation

2.1 Project overview

The solution to the problem of natural gas line protection was the installation of a cathodic protection (CP) system consisting of deep well ceramic anodes. Impressed CP systems protect the buried pipe by supplying electrons from the ceramic anodes that are made to assume a negative potential relative to the pipe. The mixed metal oxide (MMO) ceramic anodes were installed in 3 strategic locations 50–200 ft deep below the ground. Installation of deep well impressed current ceramic anode beds help to more widely distribute the protection current from ceramic anodes to protect pipelines. A new precious metal oxide coated continuous wire anode CP system was installed in the elevated water tank.

In addition, CP test stations were installed with drive by remote monitoring systems that include software that can alert base maintenance personnel of a problem with the CP current and potential readings.

2.1.1 Specifications

The cathodic protection system being placed to protect the underground gas lines had to withstand being exposed to water, had to be able to be buried 50–200 ft below ground and had to be replaceable. The CP system for the elevated water tank needed to have a longer life than the current high silicon cast-iron anode. The remote monitoring system had to be easy to use with drive by capabilities, parameter monitoring flexibility and useful to understand data output.

2.1.2 Application design details

2.1.2.1 System design details for the deep well anodes

In choosing the deep groundbed anodes several advantages and disadvantages of this type of placement were considered. Among these are the following, extracted from NACE Standard Recommended Practice RP0572-2001, *Design, Installation, Operation, and Maintenance of Impressed Current Deep Ground Beds*:

4.2 The following advantages and disadvantages are characteristic of deep groundbeds and should be considered in the design of such a groundbed:

4.2.1 Advantages

4.2.1.1 Deep groundbeds may be located in congested areas where shallow groundbeds pose geographic, topographic, interference, or right-of-way problems.

4.2.1.2 Deep groundbeds may provide lower resistance than shallow groundbeds in areas of high-resistivity surface soils.

4.2.1.3 Deep groundbeds may result in lower anodic potential gradients to other structures than shallow groundbeds.

4.2.1.4 Deep groundbeds may provide better current distribution than shallow groundbeds.

4.2.1.5 Deep groundbeds eliminate some of the accidental damage that may occur to shallow groundbeds by excavation and land cultivation.

4.2.1.6 Deep groundbeds are less affected by seasonal moisture variations than shallow groundbeds and usually are not subject to freezing.

4.2.1.7 The use of open-hole deep groundbeds or closed-hole deep groundbeds specifically designed for anode replacement can facilitate inspection, repair, and replacement of groundbed components.

4.2.1.8 Deep groundbeds minimize surface disturbances in environmentally sensitive areas.

4.2.2 Disadvantages

4.2.2.1 Current requirement tests that accurately simulate actual deep groundbed installations are difficult to conduct.

4.2.2.2 Deep groundbeds are often more expensive to install than shallow groundbeds of similar current.

4.2.2.3 Inspection, replacement, or repair of closed hole deep groundbed installations may be difficult.

4.2.2.4 Closed-hole deep groundbeds require special design considerations because of their susceptibility to gas blockage. This disadvantage may not apply to continuous steel pipe or rail groundbeds.

4.2.2.5 Supplemental shallow groundbeds may be required to provide adequate protective current distribution to certain structures, or to provide adequate potential shifts for structures located in the immediate vicinity of the deep groundbed.

4.2.2.6 Compaction of backfill material around the anode in a deep groundbed may be difficult to achieve. The use of high-density backfill material can improve compaction. Poor compaction or absence of backfill can cause accelerated deterioration of the anode.

4.2.2.7 Open-hole deep groundbeds require an aqueous electrolyte.

4.2.2.8 Open-hole deep groundbeds may require nonconductive casing to prevent cave-in.

4.2.2.9 Open-hole deep groundbeds usually require additional depth below the bottom anode to form a sump for the collection of sediment.

4.2.2.10 Prediction of deep groundbed performance is more difficult and less exact than for shallow groundbeds.

4.2.2.11 Problems may exist with the bridging of subsurface aquifers that may require special design considerations to prevent intermixing of waters.

The anode chosen for this project is a new type of ceramic anode used to protect underground pipes. They were installed in deep wells 50–100 ft deep. The deep-well ceramic anodes are in soil that has a 20–70 ft water head, and the connection between the anodes and the cable is the weakest link, which must be protected. This new ceramic anode configuration is called *tubular* as it consists of a titanium tube with an MMO ceramic coating, and a center connection, and sealed ends to protect it from water intrusion in the deep wells (Figure 1).

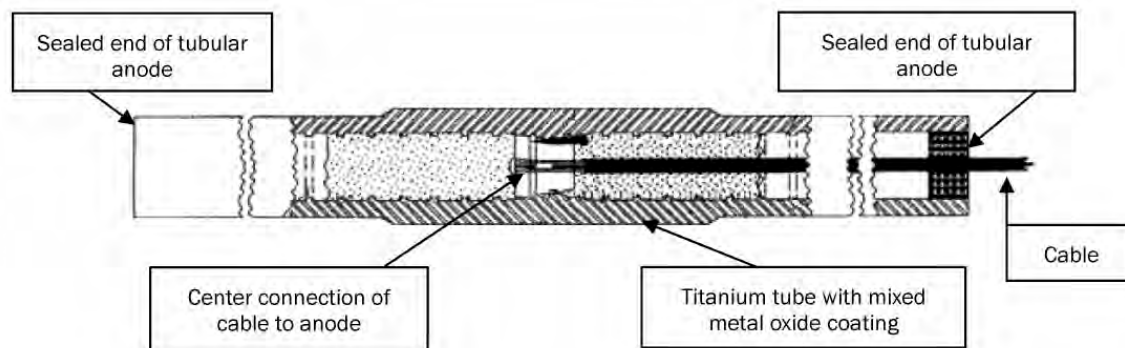


Figure 1. New tubular anode design to be used in deep anode wells at Fort Jackson.

The deep anode beds incorporate the use of double end lead wire feeding through ceramic (precious metal oxide) coated titanium anode tubes. The double end feed wire provides redundancy in case a flaw should develop in the anode wire. In addition, fluoro-polymer insulated lead wire with a high molecular weight polyethylene jacket is used. The fluoro-polymer insulation provides complete resistance to attack by any gases generated at the anode/coke breeze interface. Connection of the lead wire to the anode tube is made internally at its central most point providing the longest sealing path and thus resistance to water penetration into the connection point. The more commonly used rod type anodes cannot be double end fed eco-

nomically and cannot incorporate the long sealing path provided by the tubular shape. It was this older style anode that was used at Fort Carson.

The deep anode beds incorporate the latest design in replaceable systems which provide the same level of future ease of replacement of the anode material at significantly reduced costs by not including a steel lead and ball check valve at the bottom of the deep anode tube. Instead, the coke breeze is placed around the anode material in the conductive zone and the exterior of the perforated casing pipe simultaneously. The DW3 calcined fluid petroleum coke used on this project is both extremely conductive and has a very high density enabling it to displace any drilling materials that would otherwise remain within the deep anode bed column. These features were not incorporated into the Fort Carson project.

The area of the buried steel piping requiring protection at Fort Jackson is not known with any degree of accuracy because as-built drawings and historical records were unavailable. The area of other utility piping (e.g., water mains and distribution piping) believed to be electrically grounded to the gas piping is also unknown. Most of the gas piping system appears to be electrically shorted to these other piping systems subjecting the steel pipe of the natural gas distribution to significant dissimilar metal corrosion.

Without more information on where the gas piping is located, what other utilities are close and what material the piping is made of, it is not possible to design a meaningful CP system to protect the entire buried steel gas piping system. In view of this limitation, there was agreement between CERL and Bushman & Associates (B&A) that three (3) ceramic, deep anode groundbeds would be installed and operated to determine how much of the gas piping would be protected. Based on the results, recommendations would then be made for installation of additional deep anode groundbeds, as needed, to protect all of the gas piping. Thus, unlike a traditional design, current requirements could not be based on a specific design current density (e.g., 2 mA/ft²) for steel and known surface area requiring protection.

2.1.2.2 System design for the CP on the elevated water storage tank

The previous cathodic protection system consisted of the more commonly used (less expensive and less durable) high silicon cast-iron anodes. A cathodic protection system consisting of precious metal oxide coated conti-

nuous wire anodes suspended vertically in the water from the tank roof was chosen to replace the iron anodes. This vertical suspension was enabled by the lack of winter ice formations inside the tank in this southern climate. The new anode material connections are made above the high water line preventing the ingress of water into the connection and subsequent failure of the anode material.

This type of anode suspension from the roof of a water storage tank should only be considered for use on those tanks, which are virtually always free of significant ice formations during the winter months. Those tanks, which are subject to ice formations of more than one or 2 inches on the surface of the water inside the tank, should never incorporate this type design. Rather, they should only use the tethered hoop style system, which places the anodes significantly below the ice level in the tank, and thus prevents their damage.

The advantage of the vertically suspended anode system is that they can more easily be removed for inspection and maintenance replacement, should that be necessary in the future. The tethered hoop style anode system requires that the tank be drained before anode inspection and or replacement can be performed. The vertically suspended system is substantially less expensive to install when the environmental conditions preclude ice formations, which would damage the anode material, and clean water level fluctuations while the ice is present in the tank.

The initial system design was developed by B&A, using a computer program they developed several years ago to automate the design process for impressed current cathodic protection design for water storage tanks. The program operates within Microsoft Excel and allows multiple iterations of the design to be developed and compared for capacity and power requirements. The following shows the final design parameters after multiple iterations:

Table 1. Outer ring vertical anode calculations.

**Bare Impressed Current Ceramic Anode
Resistance and Current Output Calculations
Computation Program[®] by Bushman & Associates, Inc.**

Case Name.:

**Fort Jackson 2MMG Elevated Water Storage Tank -
Outer Ring Anodes -- Ver. 2.0 -- 31 Foot Long**

Tank & Content Variables	Value	Term
Tank Bowl Diameter	1,200	Inches
Tank Range-in-Head	480	Inches
Water Temp	55	degrees F
Water Resistivity at Hot Water Temp	8800	ohm-cm
Current Density Req'd at Hot Water Temp	2	mA/Ft ²
Tank Sumerged Surface Area	16250	Ft ²
Coating Efficiency	50%	
Total Current Required at Hot Water Temp	16250	mA

Anode Variables	Value	Term	Notes by Program Author J. B. Bushman 1. Only Blue Variables can be changed 2. All variables should be carefully considered 3. This model works for all Impressed Current Anodes 4. For different alloys, be sure to modify: a. Efficiency b. Utilization Factor c. Anode Potential d. Cathode Potential 5. This model is for Vertically Installed Anodes or for Submerged Anodes Installed in Full Containers 6. This model is for Multiple Parallel Connected Anodes
Electrolyte Resistivity	8800	Ohm-Cm	
Desired Total CP Current (includes 20% Safety Factor)	19.5	Amperes	
Anode Metal	Platinum Coated Niobium		
Anode Alloy	Copper Cored - 40% wall niobium with 25 micro-in platinum		
Anode Model No.	.025/40/Cu/Pt/Nb		
Desired Anode Life	20	Years	
Anode Mfg. Rated Current for 20 Yr Life in Fresh Water	0.020833333	A/Lineal Inch	
Anode Active Length (unsleeved)	372	Inches	
Selected Anode Maximum Rated Current for Desired Life	7.8	Ampere	
Anode Efficiency (Percent used to provide CP Current)	100.0%	% Eff.	
Percent of Total Used before Considered Depleted)	1.00	% Utilization	
Rectifier Voltage	60.00	Volts	
Desired Cathode Potential (mV vs. Cu-CuSO ₄)	0.85	Volts	
Net Anode-to-Structure Driving Potential	58.35	Volts	
Anode Diameter	0.0625	Inches	
Anode Length	372	Inches	
Anode Ring Diameter	70	Feet	
No. of Anode in Ring	10		
Anode Center-to-Center Spacing (feet)	24.43460953	Feet	

Table 2. Outer ring vertical anode calculations (continued).

Calculated Current Output with Tests for Meeting Current Requirement and Anode Life						
No. of Anodes	Anode to Electrolyte Resistance (in Ohms)	Total Anode to Electrolyte Resistance (Ohms)	Total Current Output (Amperes)	Current Output per Anode (Amperes)	Is Desired Current Output Met?	Is Anode Desired Life Met?
1	14.4509	14.4509	4.038	4.038	No	Yes
2	7.7350	7.7350	7.544	3.772	No	Yes
3	5.6638	5.6638	10.302	3.434	Yes	Yes
4	4.5178	4.5178	12.916	3.229	Yes	Yes
5	3.7817	3.7817	15.430	3.086	Yes	Yes
6	3.2655	3.2655	17.869	2.978	Yes	Yes
7	2.8816	2.8816	20.249	2.893	Yes	Yes
8	2.5840	2.5840	22.581	2.823	Yes	Yes
9	2.3460	2.3460	24.872	2.764	Yes	Yes
10	2.1510	2.1510	27.127	2.713	Yes	Yes
11	1.9879	1.9879	29.352	2.668	Yes	Yes
12	1.8495	1.8495	31.549	2.629	Yes	Yes
13	1.7303	1.7303	33.722	2.594	Yes	Yes
14	1.6266	1.6266	35.872	2.562	Yes	Yes
15	1.5354	1.5354	38.003	2.534	Yes	Yes
16	1.4546	1.4546	40.114	2.507	Yes	Yes
17	1.3824	1.3824	42.209	2.483	Yes	Yes
18	1.3175	1.3175	44.288	2.460	Yes	Yes
19	1.2589	1.2589	46.351	2.440	Yes	Yes
20	1.2055	1.2055	48.401	2.420	Yes	Yes
21	1.1569	1.1569	50.438	2.402	Yes	Yes
22	1.1122	1.1122	52.463	2.385	Yes	Yes
23	1.0711	1.0711	54.477	2.369	Yes	Yes
24	1.0331	1.0331	56.479	2.353	Yes	Yes
25	0.9979	0.9979	58.471	2.339	Yes	Yes
26	0.9652	0.9652	60.453	2.325	Yes	Yes
27	0.9347	0.9347	62.426	2.312	Yes	Yes
28	0.9062	0.9062	64.390	2.300	Yes	Yes
29	0.8795	0.8795	66.345	2.288	Yes	Yes
30	0.8544	0.8544	68.292	2.276	Yes	Yes
31	0.8308	0.8308	70.232	2.266	Yes	Yes
32	0.8086	0.8086	72.163	2.255	Yes	Yes

Table 3. Inner ring vertical anode calculations.

**Bare Impressed Current Ceramic Anode
Resistance and Current Output Calculations
Computation Program[®] by Bushman & Associates, Inc.**

Case Name.: Fort Jackson 2MMG Elevated Water Storage Tank -
Inner Ring Anodes - Ver 2.0 - 20' Long Anodes

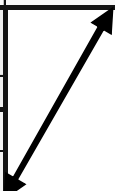
Tank & Content Variables	Value	Term
Tank Bowl Diameter	1,200	Inches
Tank Range-in-Head	480	Inches
Water Temp	55	degrees F
Water Resistivity at Hot Water Temp	8800	ohm-cm
Current Density Req'd at Hot Water Temp	2	mA/Ft ²
Tank Submerged Surface Area	16250	Ft ²
Coating Efficiency	50%	
Total Current Required at Hot Water Temp	16250	mA

Anode Variables	Value	Term	Notes by Program Author J. B. Bushman 1. Only Blue Variables can be changed 2. All variables should be carefully considered 3. This model works for all Impressed Current Anode 4. For different alloys, be sure to modify: a. Efficiency b. Utilization Factor c. Anode Potential d. Cathode Potential 5. This model is for Vertically Installed Anodes or for Submerged Anodes Installed in Full Containers 6. This model is for Multiple Parallel Connected Anodes
Electrolyte Resistivity	8800	Ohm-Cm	
Desired Total CP Current (includes 20% Safety Factor)	19.5	Amperes	
Anode Metal	Platinum Coated Niobium		
Anode Alloy	Copper Cored - 40% wall niobium with 25 micro-in platinum		
Anode Model No.	.025/40/Cu/Pt/Nb		
Desired Anode Life	20	Years	
Anode Mfg. Rated Current for 20 Yr Life in Fresh Water	0.020833333	A/Lineal Inch	
Anode Active Length (unsleeved)	240	Inches	
Selected Anode Maximum Rated Current for Desired Life	5.0	Ampere	
Anode Efficiency (Percent used to provide CP Current)	100.0%	% Eff.	
Percent of Total Used before Considered Depleted)	1.00	% Utilization	
Rectifier Voltage	60.00	Volts	
Desired Cathode Potential (mV vs. Cu-CuSO ₄)	0.85	Volts	
Net Anode-to-Structure Driving Potential	58.35	Volts	
Anode Diameter	0.0625	Inches	
Anode Length	240	Inches	
Anode Ring Diameter	20	Feet	
No. of Anode in Ring	5		
Anode Center-to-Center Spacing (feet)	15.70796327	Feet	

Calculated Current Output with Tests for Meeting Current Requirement and Anode Life

No. of Anodes	Anode to Electrolyte Resistance (in Ohms)	Total Anode to Electrolyte Resistance (Ohms)	Total Current Output (Amperes)	Current Output per Anode (Amperes)	Is Desired Current Output Met?	Is Anode Desired Life Met?
1	21.3942	21.3942	2.727	2.727	Yes	Yes
2	11.4897	11.4897	5.078	2.539	Yes	Yes
3	8.4488	8.4488	6.906	2.302	Yes	Yes
4	6.7564	6.7564	8.636	2.159	Yes	Yes
5	5.6657	5.6657	10.299	2.060	Yes	Yes
6	4.8988	4.8988	11.911	1.985	Yes	Yes
7	4.3275	4.3275	13.484	1.926	Yes	Yes
8	3.8840	3.8840	15.023	1.878	Yes	Yes
9	3.5288	3.5288	16.535	1.837	Yes	Yes
10	3.2375	3.2375	18.023	1.802	Yes	Yes

Table 4. Summary of design output calculations.

Fort Jackson 2MMG Hydro-Pillar Style Elevated Water Storage Tank - ICCP System Output Calculations - Reference Worksheet Tabs 2 and 3		
	Resistance	Current Output at Rectifier Rated Voltage
Outer Ring Anode Strings	2.1510	27.13
Inner Ring Anode Strings	5.6657	10.30
Total ICCP System Designed Current Output Capacity		37.43
Check - Anode Resistance of all anodes in parallel - Ohms	1.56	
Check - Calc. Current - Amperes	37.52	
Total Submerged Bowl Area (Ft ²)	16250.00	
Total Current Required assuming 75% efficient coating and 2 mA/ft ² required for effective ICCP	16.25	

2.1.2.3 Remote monitoring design

A comparison of wireless technologies for remote monitoring of CP systems had been made prior to the start of this work (Table 5). Some of this research was presented as a paper at the NACE 2007 conference, and is included in Appendix A.

Table 5. Comparison of remote monitoring technologies.

	SCADA-Based System	Drive-by System	Cell phone-Based System	Satellite Based System
Initial Cost	\$10,000 per monitoring station	\$2,000 per monitoring station	\$2,000 per monitoring station	\$500-700 per station
Maintenance Requirements	Moderate	Low	Low	Very low
Advantages	<ul style="list-style-type: none"> -Takes advantage of existing wireless system -can take readings at any time -can control remotely from a central location at any time -can interface with GIS system 	<ul style="list-style-type: none"> -Low installation cost - can easily be installed - broadcast frequencies are pre-approved 	<ul style="list-style-type: none"> -Low installation cost - can easily be installed - can take readings at any time - broadcast frequencies are pre-approved - can control remotely any location at any time 	<ul style="list-style-type: none"> -Monitor CP system virtually anytime, any where in the world through the internet
Disadvantages	<ul style="list-style-type: none"> High cost -Signal path must be properly planned for adequate transmission Signals must be line of site (LOS) -Signals are sometimes lost if there are impediments to LOS - FCC approval is needed for new SCADA frequencies 	<ul style="list-style-type: none"> -Can not monitor from central location; must drive by within 0.1 mile of monitoring station 	<ul style="list-style-type: none"> -Cost of cell phone services -Cell phone signals are sometimes lost in certain locations 	<ul style="list-style-type: none"> -Charges fee/reading/location -Line of site limitations
Recommendation	<ul style="list-style-type: none"> -Use where existing SCADA system is available, such as water tanks -Do not install additional SCADA systems 	<ul style="list-style-type: none"> -Use where there are no existing SCADA systems -Use when drive by systems are viable 	<ul style="list-style-type: none"> Use where there are no existing SCADA systems -Use where drive by systems would not be viable- very remote areas 	<ul style="list-style-type: none"> Use where there are no existing SCADA systems -Use where drive by systems would not be viable- very remote areas

The use of drive by RMU systems versus those utilizing satellite based interrogation systems or SCADA systems is merely a matter of economics and the frequency that data acquisition is required. Since cathodic protection data acquisition is typically only required once each month, the cost of installing SCADA equipment at each cathodic protection test Station is simply not practical. Thus at US army facilities, the use of SCADA systems will only be practical at those locations where they already exist for other

measurement and control purposes. Satellite systems may be cost competitive in the near future however they typically can only communicate in one direction. The drive-by system can communicate in both directions sending corrections and testing parameters to the monitor unit and receiving data based on the monitor parameters transmitted. The drive-by system is particularly economic for military facilities where the monitor points are relatively closely spaced geographically.

An upgraded remote monitoring unit (RMU) from what was used at Fort Carson was chosen for Fort Jackson. The system was designed to allow considerably more flexibility to the user in terms of increased distances for monitoring, types of systems that could be monitored by the system, variation of when data was taken and the big advantage of the data being presented in an excel data sheet clearly stating whether the CP is functioning or not.

2.2 Installation and calibration

2.2.1 Buried gas lines

An integral part of this project was to install 100 remote monitoring units to allow drive-by data collection for determining the level of CP being achieved on the buried gas lines. B&A conducted a 2-week-long corrosion survey to locate and mark candidate locations for these units. The locations selected consisted of pressure-reducing test stations (PRTSs) or service entry points into buildings; examples of these are shown in Figure 2 and Figure 3, respectively. The native pipe-to-soil potentials measured at the 100 proposed remote monitoring test stations are described later.



Figure 2. Typical pressure reducing test station (PRTS).



Figure 3. Typical gas line service entry into building.

The original design called for installation of the deep groundbed anodes at a depth of 100 ft in deep wells that would be drilled at three locations. B&A made several visits to Fort Jackson and held detailed discussions with various DPW personnel. It was stated that the precise geology of the soil at the proposed anode deep wells would only be known when drilling was actually done. DPW facilitated in the application and approval process for environmental permits required by the State of South Carolina for wells deeper than 50 ft. The anode locations were selected after the aforementioned 100 remote monitoring locations were identified to provide a reasonably even distribution over the gas piping system.

B&A subcontracted the installation of the deep anode beds to Loresco, Inc. of Hattiesburg, MS. Loresco was selected because it invented the replaceable deep anode system which B&A elected to use on this project. This type system has the distinct advantage in that the anode material can usually be replaced easily in the future without redrilling the anode hole, which is a major portion of the cost of deep anode bed systems. Loresco, in turn, utilized the services of Clearwater Drilling Company of Columbia, South Carolina to perform the actual drilling of the 12 in. diameter holes to the specified depth (or to a depth where bedrock was encountered at < 100 ft).

Clearwater commenced drilling on 29 August 2007 in the open space at the intersection of Hill and Hardee Streets (across from the Central Energy Plant CEP#2) building. As requested by Fort Jackson DPW, all holes were dug by hand for the first 5 ft before using the mechanical drilling. As stated previously, there were no accurate maps of the underground infrastructure (including water, sewer, natural gas and buried communication cables) and DPW did not want to risk damaging any critical components. Further, DPW did not have any means for locating these facilities prior to installation of the anodes. The maximum depth reached at this site was ~ 65 ft before bedrock was encountered. With concurrence of Fort Jackson DPW personnel, B&A made the decision to dig a second hole ~ 50 ft away (parallel to the street). This hole also reached a depth of ~ 65 ft. Two ceramic MMO tubular anodes were installed in each well. All trenching for cables to a depth of 24 ft minimum from the anode groundbeds to the transformer/rectifier (T/R) was also dug by hand, as requested by DPW. This typically amounted to trench lengths from 50–100 in..

At the second location (intersection of Washington Rd and Hall St; ~ 1000 ft from CEP # 3), the first hole that was drilled reached bed rock at a depth

of ~ 40 ft. B&A elected to drill a second hole ~50 ft east of the first hole. It also encountered bedrock at ~ 40ft. Two ceramic MMO anodes were installed in each well.

At the third site (CEP#1), utilities including piping and communication cable were encountered during the hand digging at the initially selected deep anode bed location. Another nearby location was selected, and in accordance with the directions of the DPW, this site was then hand dug to a depth of 5 ft followed by rotary drilling. A final depth of almost 80 ft was achieved at this site before hitting bed rock. Since no other locations were available at this site, four ceramic MMO anodes were installed in the single well. Extremely long trenches had to be hand dug both to the T/R and to the natural gas pipeline at this location.

At all 3 deep anode groundbed locations described above, perforated PVC casings and the ceramic MMO anodes were installed by Loresco; and the holes filled with fine granular, conductive carbon backfill (Loresco DW3 extra-high-grade, calcined fluid petroleum coke breeze). Loresco also mounted the T/Rs and anode junction boxes on pre-existing power poles at each site. Each T/R was rated at 60V/34A DC maximum output. A DPW subcontractor installed 120VAC 60Hz 1PH power fused disconnects with switches on each power pole on the opposite side from each T/R.

Figure 4–Figure 17 depict various activities and hardware associated with the deep groundbed anodes installed at Fort Jackson.



Figure 4. Drill truck setup.



Figure 5. Overflow pan on right and coke breeze in front of drill rig.



Figure 6. Solid perforated pipe to be located at anode depth, solid pipe above anodes, and small vent pipe entire length of column.



Figure 7. Tubular ceramic anodes pre-attached to vent pipe before loading into column.



Figure 8. Loading anodes and vent pipe into column.



Figure 9. Alternate view of loading anodes and vent pipe.



Figure 10. Mixing DW-3 coke and pumping into column.



Figure 11. Fine sand encountered at all depths in southmost deep anode bed.



Figure 12. Top of deep anode column after anodes, vent pipe, and coke breeze installed



Figure 13. Portion of hand-dug trench (24 in. minimum)



Figure 14. Deep anode access box and hand-dug trench between pipe and rectifier,



Figure 15. Deep anode access box.



Figure 16. Rectifier power supply and anode junction box, Wall and Washington Streets.



Figure 17. Rectifier power supply and junction box, Hardee and Hill Streets.

2.2.2 Elevated storage tank

ERDC-CERL specified installation of ceramic MMO anodes for the interior CP of the 2 million gallon elevated water storage tank to replace the existing silicon-iron anodes that had failed. CP of the tank interior is only effective below the waterline. CP and a coating system on the tank interior are complementary; coating reduces CP current demand and CP prolongs coating life. Tank data are provided below:

- Manufacturer: Pitt-Des Moines, Inc.
- Year built: 1991
- Capacity: 2,000,000 gallons
- Diameter: 100 ft
- Height: 64 ft

For installation of the new CP system on the water tank, the subcontractor, Freeman Industries (Dorset, OH) removed the existing rectifier, reference cell, anodes, under-roof wiring, insulators, and roof plates. New anodes, reference cell, insulators with stainless steel hardware, under-roof wiring, roof anode access hand-hole plates, and rectifier were installed. The existing mainline conduit between the interior base of the tank and the roof were left in place and used with the new system. New reference cell and structure grounds were installed using tapped holes and stainless steel bolts. New CP system information is provided below:

- Rectifier
 - Manufacturer: Integrated Rectifier Technologies, Inc.
 - Model: CIASFS 60-34 LMaOxQaVW, Type CP Sentinel Rectifier
 - 60 v, 34 amp rated DC output with 120/240 v, 60 Hz, single phase AC input; IR-drop free potential controlled DC output circuit with optional manual control.
 - Serial Number: 07R-0411.
- Anodes:
 - The anodes consist of two concentric rings of vertically suspended .062" diameter ceramic wire anodes in the following configuration:
 - Ring 1 (outer)–10 anodes suspended vertically from the roof of the tank uniformly spaced on a 35' radius circle, each with 33' of ceramic anode wire.
 - Ring 2 (inner)–5 anodes suspended vertically from the roof of the tank uniformly spaced on a 10' radius, each with 20' of ceramic anode wire.

The anodes are suspended from #10 RHW/USE wires and are attached to the tank roof by using pin insulators with stainless steel hardware. New hand-hold/access plate covers are located next to each anode for installation and servicing purposes. Each hand-hole is covered with an acrylic roof plate. The anodes are electrically connected to each other with #10 RHW/USE under roof wires which are run between the insulators and then to the mainline wire to the rectifier. A diagram of this tank cathodic protection system configuration is shown in Figure 18.

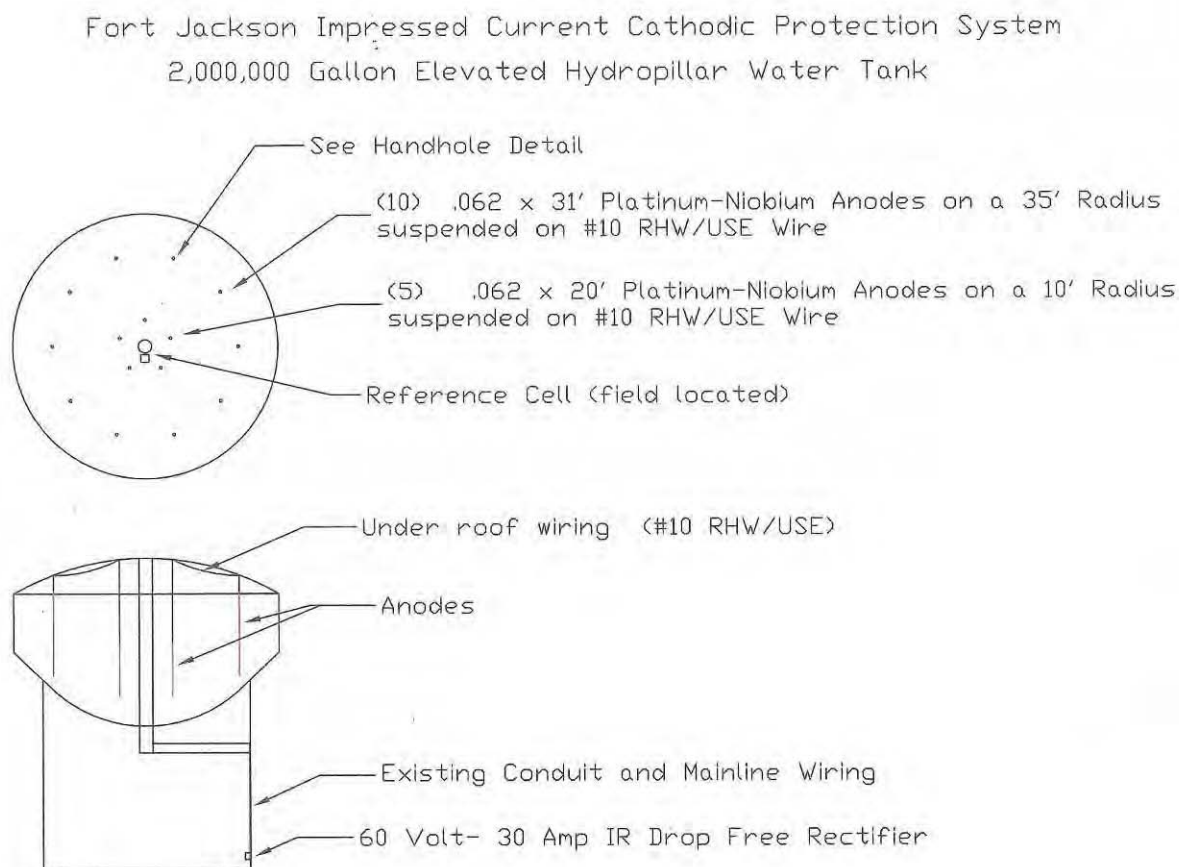


Figure 18. Diagram of storage tank CP system configuration.

2.2.3 Rectifier power supply and controller

The impressed current rectifier power supply selected for providing the energy to the ICCP system was of the automatic potential control type. Further, it was designated to utilize “IR drop free potential control” as the principal means for adjusting the system current output automatically. The supplier chosen for this rectifier unit was Integrated Rectifier Technology (IRT) with over 20 years of experience in manufacturing this rec-

tifier. The faceplate of the rectifier is shown in Figure 19. A copy of the operating manual for this rectifier is included in Appendix B.



Figure 19. IRT rectifier faceplate.

The IRT rectifier can also be operated in manual mode or in constant current mode. The mode of operation is indicated by LED lights observable in the upper right-hand corner of the rectifier faceplate (Figure 19). The unit is a solid-state design with modular construction. The rectifier cabinet has side as well as front opening doors to facilitate replacement of any module should that become necessary in the future.

2.2.4 Reference electrode

An Electrochemical Devices Inc. (EDI) Model IR Cu-CuSO₄ reference cell was suspended inside the tank bowl about 3 ft from the access tube and 8 ft up from the bottom of the tank.

2.2.5 DC positive, negative, and reference cell wiring and conduit

The existing 0.75 in. galvanized conduit carries two AWG 4 wires and a 2 wire (AWB 18) twisted pair control cable from the rectifier to the top of the tank. The AWG 4 wires were used for the rectifier anode connection (+) and the rectifier structure (-) connection. The two-wire control cable transmits the reference cell potential and structure potential to the rectifier controller for automatic potential control.

2.2.6 System performance

The anode resistance was measured to be 1.9 ohms with the water level 15 ft below overflow by using a Nilsson Model 400 Soil Resistance Meter. Given that the water level was down 15 ft, this is excellent correlation with the design calculations shown in the design section.

The reference cell resistance was measured to be 3000 ohms with the water level 15 ft below overflow by using a Nilsson Model 400 Soil Resistance Meter. Typically, permanent reference electrodes installed in water storage tanks have resistances less than 10,000 ohms.

Before the new CP system was energized on 5/29/07, the native potential with respect to the EDI Cu-CuSO₄ reference cell was measured to be -0.434 volts. After energizing, the potential measurements were in the -0.890 to -0.930 V range from top to bottom, indicating that the submerged surfaces were completely protected from corrosion in accordance with NACE International Recommended Practices, while the uniformity of this corrosion control was also exceptional.

2.3 Technology operation and monitoring

Properly monitored CP systems help to verify if sufficient corrosion control is being achieved for the structure(s) intended to be protected. Monitoring serves as the basis of establishing proper CP system commissioning, routine operation and maintenance; and demonstrating efficacy of any corrective actions. The traditional monitoring method involves determina-

tion of structure-to-soil potentials at conveniently-located test stations. The potential of the structure is measured with the aid of a high-impedance DC voltmeter and a reference electrode (e.g., Cu/CuSO₄ half cell) while the CP rectifier is turned off and on automatically. If there are a large number of test stations, manual measurements obviously are very time consuming. Monitoring can be automated in a number of ways. Presently, one very attractive approach is through the use of remote monitoring units (RMUs). In this project, DART RMUs (Borin Manufacturing, Culver City, CA) were used. Each unit consists of a data logger and radio transmitter incorporated into a very small battery-powered device that fits easily inside a 4 in. diameter PVC test post (Appendix C). The device is hard-wired through the test post interior to a permanent Cu/CuSO₄ half cell buried in the soil below. The RMU is powered by a long-life battery. The data stored in the DART can be downloaded during drive-by in a vehicle equipped with an antenna and laptop computer. A coupled GPS system aids the location of the test stations and software verifies that the data have been collected successfully.

Figure 20 and Figure 21 show a typical DART and test station, respectively. Bare carbon steel coupons incorporated into a Cu/CuSO₄ half cell are shown in Figure 22. Because of their very close proximity to the tip of the half-cell, the coupons are very useful in determining “ON” and “OFF” potentials of the structure being protected because IR drop errors are largely eliminated. Figure 23 shows the laptop computer used for the DART drive-by data acquisition. Figure 24 is a closer view of the display showing the GPS system during the drive-by data collection from the DARTs; the normal dots (red) showing the DART test station locations change color (to white) as they are successfully read during the drive-by. Special DART units were also installed in the TRs to collect T/R data; Figure 25 and Figure 26 show a typical unit.



Figure 20. DART RMU with cap removed.



Figure 21. DART RMU test station in place.



Figure 22. Cu/CuSO₄ reference electrode with integral main and spare coupons.



Figure 23. Drive-by data collection system including GPS-enabled laptop computer.

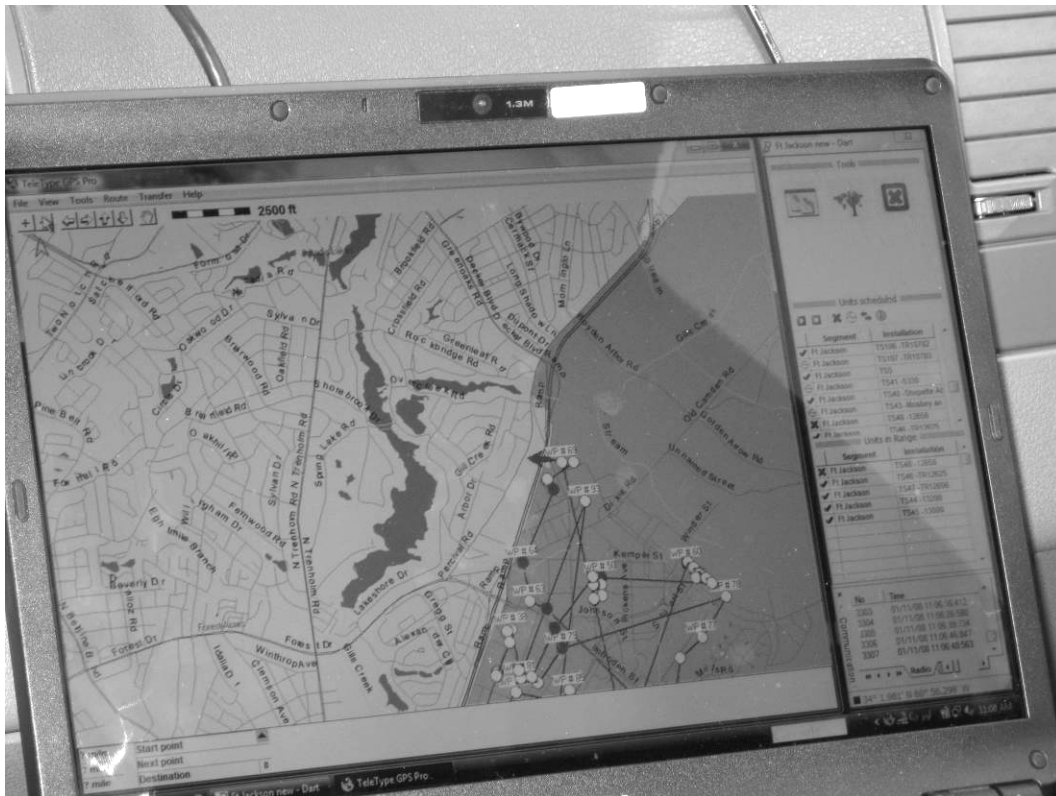


Figure 24. Laptop screen showing GPS locations of RMUs (dots at lower right).



Figure 25. RMU rectifier reader unit inside rectifier cabinet, cover removed.



Figure 26. Close-up view of RMU rectifier reader unit.

2.4 Data collection and logging

The remote monitoring system installed at Fort Jackson utilizes an upgraded portable drive-by interrogation system from that at Ft. Carson, installed in a standard PC portable computer. The new system is capable of operating on computers running Windows Vista, XP, or 2000. It utilizes more powerful radios in both the test station monitoring units and the mobile data acquisition system increasing both the distance and the speed with which data can be acquired from the test stations. The new system reduces the time for data acquisition on a typical base wide system from less than eight hours to less than two hours. Increased capacity batteries have also been incorporated into the new design test station units increasing the frequency with which the units may be interrogated (from once a month to once a week) while still maintaining an operating life of more than 10 years before battery replacement is required.

The degree of flexibility provided by the new software furnished with the latest version of this drive-by RMU system has greatly increased the applicability of the RMU. All measurement parameters including time between data samples, length of time period during which instant off potentials are

measured and time period over which polarization decay is assessed are all user selectable values. Thus the system can now be utilized on other pipe materials such as ductile iron, aluminum and copper which have different criteria for cathodic protection than that used on buried steel pipe. Software setup and use has been greatly simplified by the PC-based system with intuitive drop-down menus and screen presentations

The DART units installed at Fort Jackson are set to collect the data once weekly, on Monday. The data can then be read during the drive-bys either on Tuesday or Wednesday. For the remainder of the week the DART units are in a “sleep” mode to conserve battery power, which is guaranteed for 15 years. The data from the 100 remote monitoring units as well as from the water storage tank can be collected through the drive by method. These data are then automatically transferred into an Excel spreadsheet where it is automatically analyzed on a pass/fail basis. The Fort Jackson personnel just have to look at the table to see if there are any trouble spots.

3 Discussion

3.1 Metrics

The remote monitoring system is monitoring 100 CP test stations and the DC voltage and current from ICCP system rectifiers. The test station systems measure the structure protection levels on a coupon that is normally connected to the structure and thus receiving the same level of CP as the structure. At a user selectable time interval, typically once each week, the test station reader automatically decouples the coupon for another user selectable time period (typically 0.5–1 second) during which it automatically measures and records the instant off IR-drop free potential of the coupon. The potential is measured with respect to an integral permanent copper-copper sulfate reference electrode. If the coupon reading is -850 mV or more negative (this value can be set higher or lower by the user), the test is complete and the monitoring system becomes dormant for 1 week, at which time it repeats the measurement. A total of up to 12 readings are stored in the unit after which the oldest reading is cleared out and a new reading is stored in the memory, thus the 12 most recent readings are always available for interrogation by the portable drive-by data acquisition system.

If the weekly instant off reading is more positive than -850 mV (e.g., -750 mV), then the unit goes into a polarization decay mode, whereby it leaves the coupons decoupled from the structure for a user selectable time interval (NACE normally recommends a time interval (NACE RP-0169) of 4 hours). At the end of this time interval, the unit measures the value of the decayed potential and subtracts this value from the instant off value, in accordance with NACE criteria RP-0169. So long as the decay thus measured and calculated is greater than 100 mV, CP is confirmed on the coupon and the structure on which it is attached.

The rectifier reader unit measures the same values for a coupon installed near the rectifier and, in addition, measures the rectifier output DC voltage and current. The current is measured across the rectifier shunt resistor in mV and is converted to amperes using Ohm's Law. IR-Drop Free Potentials measured in this manner on the coupons were found to be within +/- 5 mV of the value similarly measured by a Fluke model 867 precision Volt-ohm meter (VOM), while the rectifier voltage and current values were

tested similarly and were within a tolerance of $\pm 2\text{mV}$ and $\pm 200\text{mA}$, thus verifying that the CP system and RMUs were operating as designed.

3.2 Results

On the water storage tank, before the new CP system was energized on 29 May 2007, the native potential with respect to the EDI Cu-CuSO₄ reference cell was measured to be -0.434 volts. After energizing, the potential measurements were in the -0.890 to -0.930 V range from top to bottom, indicating that the submerged surfaces were completely protected from corrosion in accordance with NACE International Recommended Practices while the uniformity of this corrosion control was also exceptional.

The drive-by survey, typically performed by one person, reads all 100 DART stations and all the TRs (including the elevated water storage tank) in about 3 hours. In contrast, it is estimated that manual measurements of all these locations would probably take about 1 week.

In March 2007, a baseline native potential survey was performed at all the test locations where the DART units were intended to be installed. The data are summarized in Appendix D. It was noted that CP was being provided very locally at a few locations from the existing “old” CP system. The vast majority of the test locations indicated that the buried piping was unprotected; in many instances the potentials suggested that the steel was in contact with other structures such as copper grounding rods.

In October 2007, before the three deep anode groundbed systems were energized, another baseline potential survey performed (Appendix D). Data could not be collected from some test stations because of military activities under way on base at the time.

T/R data collected during the course of the demonstration are summarized in Appendix E.

The data collected to date are shown in Appendix G. The data indicate that approximately 20 to 30% of the buried gas piping is receiving varying levels of cathodic protection which can change with time as polarization continues. A reading showing 25–100% cathodic protection at the test station is considered passing. The data were simplified into either a pass or fail condition on the excel printouts the system provided (Appendix F).

3.3 Lessons learned

On many installations piping and other underground systems have been replaced or moved and documentation of these changes have not been consistently recorded in one easy to access place. Fort Jackson is one such installation where accurate historical and current as-built drawings for the underground systems were not readily available. When this is the case, the first part of digging for installation of deep well anodes, has to be performed by hand so that crucial communication, piping or other systems are not inadvertently disrupted. This also means that there has to be a contingency plan if the original planned site is where there are existing systems. Along with the initial digging for the well being done by hand, there also has to be trenches dug by hand to install the cabling connecting the anode groundbeds to the TRs. These trenches are typically 24 in. minimum in depth.

The many variances in the soil types and depths at Fort Jackson presented another need for having contingency plans as bedrock was encountered at varying depths. The first two sites for the deep bed anodes reached bedrock at around 65 ft and 40 ft, respectively. These sites each got two holes and two anodes were installed in each well. But, the third site hit bedrock at 80 ft. Since there was no other site available to dig because of underground utilities encountered on the first digging, 4 ceramic anodes went into the one well. This third site also required considerable trenching to connect the anodes to the gas pipeline and the T/R.

The baseline native potential survey performed indicated that many of the test locations were not being cathodically protected. The potentials indicated that the steel was in contact with other structures such as copper grounding rods. It is also suspected that there are small segments of plastic pipe installed within the steel piping system making it difficult to determine if complete CP is being provided.

If the piping system is not properly isolated, cathodic protection of the system is much more difficult to achieve.

4 Economic Summary

4.1 Costs and assumptions

The benefits of implementing CP systems on the subject infrastructure are bringing mission-critical natural gas piping infrastructure into compliance with legal requirements, reducing maintenance requirements and costs, and improving infrastructure safety, readiness, and reliability.

Table 6 lists the cost of implementing the subject technology at Fort Jackson.

Table 6. Funding sources (\$K).

Funding Source	OSD	Service Matching
Labor	220	230
Materials	200	200
Travel	30	30
Report	40	40
Air Force/Navy Participation	10	-
TOTAL (\$K)	500	500

- (1) Useful Life Savings (ULS) is equal to the “Net Present Value (NPV) of Benefits and Savings” calculated from the Spreadsheet shown in Table 7, which is based on Appendix B of OMB Circular A94.
- (2) **ULS= \$ 14,682 K**, from OMB Spreadsheet in Table 7. Assumptions for this calculation are also given in Table 7.
- (3) Project Cost (PC) is shown as “Investment required” in OMB Table 7; **PC= \$1,000K**.
- (4) ULS \$14,682K

$$\text{ROI} = \frac{\text{ULS}}{\text{PC}} = \frac{\$14,682\text{K}}{\$1,000\text{K}} = 14.7$$

4.2 Return-on-investment computation

Assumptions for two alternate scenarios are summarized below.

Scenario 1: Fort Jackson has the following systems that are in need of cathodic protection (CP) and remote monitoring systems in order to insure that the CP systems are properly maintained: (1) underground natural gas pipelines, and (2) a potable water storage tank. The natural gas lines will need to be replaced in years 5 and 25 at a cost of \$14.3 M each year. Average annualized maintenance costs are \$50K, before replacement. After replacement, the annual maintenance costs again increase until rehab. in year 20 at a cost of \$2 M, then decline (because of the rehab.) until the next major replacement. The cost for replacement of the water storage tank in year 10 is \$2 M. All of these costs are shown under *Baseline Cost* in the ROI Spreadsheet.

Additional costs, shown in Spreadsheet 1b (Table 8) will be for excavation to fix and repair leaks to the underground lines, emergency bottled water, and fire suppression water trucks standing by in case of fires and explosions from gas leaks. These costs are initially \$120K and they decrease in year 5, only to increase again in year 10 to \$100,000, when the most of the new systems are installed. Afterward, these additional costs track prior history, decreasing in years 20 and 25, when there is a rehab or replacement and increase afterwards up to \$20K, as shown in Table 8.

Scenario 2: Cathodic protection upgrades and remote monitoring of the CP system will be implemented in year 1, for the water storage tanks, and natural gas lines at an investment cost of \$1,000K. Average annualized maintenance costs will be \$25K–\$30 K to maintain the CP system, as well as the tanks and pipes, as shown in the ROI Spreadsheet under *New System Costs*. Also, shown under *New System cost* is the cost of rehab of the CP systems in year 20 at \$2M. Comparing the two alternatives, the return-on-investment for Alternative 2 is 14.7.

Table 7. ROI calculation spreadsheet 1a.
Return on Investment Calculation

Investment Required			1,000,000
Return on Investment Ratio	14.68	Percent	1468%
Net Present Value of Costs and Benefits/Savings	837,118	15,519,595	14,682,477

A Future Year	B Baseline Costs	C Baseline Benefits/Savings	D New System Costs	E New System Benefits/Savings	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1	170,000		25,000		23,365	158,882	135,517
2	170,000		25,000		21,835	148,478	126,643
3	170,000		25,000		20,408	138,771	118,364
4	170,000		25,000		19,073	129,693	110,621
5	14,350,000		25,000		17,825	10,231,550	10,213,725
6	70,000		25,000		16,658	46,641	29,984
7	81,000		25,000		15,568	50,439	34,871
8	92,000		25,000		14,550	53,544	38,994
9	103,000		25,000		13,598	56,022	42,424
10	2,114,000		25,000		12,708	1,074,546	1,061,839
11	35,000		30,000		14,253	16,629	2,376
12	43,000		30,000		13,320	19,092	5,772
13	50,000		30,000		12,450	20,750	8,300
14	62,000		30,000		11,634	24,044	12,410
15	68,000		30,000		10,872	24,643	13,771
16	75,000		30,000		10,161	25,403	15,242
17	87,000		30,000		9,498	27,544	18,046
18	95,000		30,000		8,877	28,111	19,234
19	102,000		30,000		8,295	28,203	19,908
20	2,001,000		2,000,000		516,800	517,058	258
21	42,000		25,000		6,038	10,143	4,106
22	50,000		25,000		5,643	11,285	5,643
23	60,000		25,000		5,273	12,654	7,382
24	65,000		25,000		4,928	12,812	7,884
25	14,301,000		25,000		4,605	2,634,244	2,629,639
26	15,000		25,000		4,305	2,583	-1,722
27	20,000		25,000		4,023	3,218	-805
28	26,000		25,000		3,760	3,910	150
29	32,000		25,000		3,515	4,499	984
30	32,000		25,000		3,285	4,205	920

Table 8. ROI calculation spreadsheet 1b.

	Baseline Costs					New System Costs		
	Gas Line			Tank				
Year	Maintain	Replace/Rehab.	Repair	Replace	Total	Maintain	Rehab	Total
1	\$50,000		\$120,000		\$170,000	\$25,000		\$25,000
2	\$50,000		\$120,000		\$170,000	\$25,000		\$25,000
3	\$50,000		\$120,000		\$170,000	\$25,000		\$25,000
4	\$50,000		\$120,000		\$170,000	\$25,000		\$25,000
5		\$14,300,000	\$50,000		\$14,350,000	\$25,000		\$25,000
6	\$10,000		\$60,000		\$70,000	\$25,000		\$25,000
7	\$11,000		\$70,000		\$81,000	\$25,000		\$25,000
8	\$12,000		\$80,000		\$92,000	\$25,000		\$25,000
9	\$13,000		\$90,000		\$103,000	\$25,000		\$25,000
10	\$14,000		\$100,000	\$2,000,000	\$2,114,000	\$25,000		\$25,000
11	\$15,000		\$20,000		\$35,000	\$30,000		\$30,000
12	\$18,000		\$25,000		\$43,000	\$30,000		\$30,000
13	\$20,000		\$30,000		\$50,000	\$30,000		\$30,000
14	\$22,000		\$40,000		\$62,000	\$30,000		\$30,000
15	\$23,000		\$45,000		\$68,000	\$30,000		\$30,000
16	\$25,000		\$50,000		\$75,000	\$30,000		\$30,000
17	\$27,000		\$60,000		\$87,000	\$30,000		\$30,000
18	\$30,000		\$65,000		\$95,000	\$30,000		\$30,000
19	\$32,000		\$70,000		\$102,000	\$30,000		\$30,000
20		\$2,000,000	\$1,000		\$2,001,000		\$2,000,000	\$2,000,000
21	\$37,000		\$5,000		\$42,000	\$25,000		\$25,000
22	\$40,000		\$10,000		\$50,000	\$25,000		\$25,000
23	\$45,000		\$15,000		\$60,000	\$25,000		\$25,000
24	\$45,000		\$20,000		\$65,000	\$25,000		\$25,000
25		\$14,300,000	\$1,000		\$14,301,000	\$25,000		\$25,000
26	\$10,000		\$5,000		\$15,000	\$25,000		\$25,000
27	\$10,000		\$10,000		\$20,000	\$25,000		\$25,000
28	\$11,000		\$15,000		\$26,000	\$25,000		\$25,000
29	\$12,000		\$20,000		\$32,000	\$25,000		\$25,000
30	\$12,000		\$20,000		\$32,000	\$25,000		\$25,000

5 Conclusions and Recommendations

5.1 Conclusions

Three deep anode impressed current groundbeds installed at Fort Jackson appear to be providing varying degrees of cathodic protection to the buried gas piping system. The level of protection can change with time as polarization continues. Data collected so far indicate that only 20–30% of the buried gas piping is receiving varying levels of cathodic protection (Appendix F). Some of the piping appears to be electrically isolated from the CP system due to the intermittent use of plastic pipes at various locations in the gas line.

The new cathodic protection system in the elevated water storage tank is providing complete and uniform protection in the tank interior below the waterline. The anode life of the new ceramic wire anode material is conservatively calculated at greater than 40 years in this particular water storage tank.

The remote DART monitoring system appears to be working well. Drive-by surveys can be typically performed in approximately 3 hours for all 100 test stations, including rectifiers. It is estimated that a manual survey of the same items would take up to a week.

At the present time not enough data have been collected to precisely determine the requirements for providing CP to protect all buried gas piping at Fort Jackson. Gas line CP data will continue to be collected monthly through September 2008. These data will be provided to the government for purposes of determining system-wide CP requirements.

Preliminary results indicate that cathodic protection could be extended to all the underground metallic natural gas piping with the addition of 10–30 shallower (smaller; depth approximately 40–50 ft each) semi-deep anode beds of 5–10 amperes capacity each.

5.2 Recommendations

5.2.1 Fort Jackson gas line application

It appears that there may be small segments of plastic pipe installed within the steel pipe line. If this is the case, some of the protective current distribution will be non-uniform, and may even create the conditions for stray-current corrosion at these locations. It is essential that the DPW investigate whether such plastic pipe insertions exist between adjacent steel pipe sections within the gas distribution system. If such locations are found, continuity testing should be performed to determine if these separate steel sections are electrically continuous through other connections in the gas distribution system. If such continuity does not exist, it should be restored using standard bonding techniques.

One suggestion is that electrical isolation of the natural gas system from other underground utilities should be attempted, but this type of isolation could be expensive to perform and would be extremely difficult to maintain. An alternative would be that all utilities (with the exception of unbonded, electrically discontinuous ductile iron piping) be bonded together electrically and cathodically protected as one mass utility infrastructure using the aforementioned ICCP semi-deep anode beds.

5.2.2 General technology applicability

CP upgrades using deep anode beds should be used for all underground piping which have electrical continuity.

Remote monitoring units should be used to monitor CP system performance regularly for underground pipes and water storage tanks.

Where ice of 1–2 in. thickness does not form in the water storage tank during the year, the vertically suspended CP system designed for this water storage tank is a good choice.

5.2.3 Implementation

This technology is recommended for use at Army and DoD Installations for corrosion protection of utilities. Recommended revisions to existing UFGS -26 42 15.00 10, *Cathodic Protection System (Steel Water Tanks)*, and UFGS -26 42 17.00 10, *Cathodic Protection System (Impressed Current)*, are planned. Revisions will include the specifications and instruc-

tions for installing the deep bed anode impressed current CP systems. In addition, specifications for the remote monitoring units for utilities will be included.

In UFGS-26 42 17.00 10, a new paragraph describing “tubular anodes” needs to be added after 2.1.3 using the description presented in this report. Paragraph 3.5.9 should be modified to incorporate the capability to use drive by remote monitoring units using the information provided in this report as the criteria for installation and capabilities of the system.

In UFGS-26 42 15.00 10, add to paragraph 2.1.3.1 an example of a selection that can be made for an installation that does not experience 1-2” of ice in the water tank, is the precious metal anodes chosen for this project installed using a vertically suspended anode system. A paragraph also needs to be added after 3.5.1.3 that facilitates the use of the drive by remote monitoring systems, when there is not a SCADA system already in use, for testing and recording of data for the CP in the tanks.

Appendix A: Comparison of Wireless Technologies for Remote Monitoring of Cathodic Protection Systems (NACE 2007)

COMPARISON OF WIRELESS TECHNOLOGIES FOR REMOTE MONITORING OF CATHODIC PROTECTION SYSTEMS

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ABSTRACT

Impressed current cathodic protection (CP) systems for water storage tanks must be periodically tested in order to ensure proper performance. Wireless remote monitoring technologies provide the ability to monitor CP system performance data from remote locations using modem-equipped personal computers. Data can be provided to a central location through an existing supervisory control and data acquisition (SCADA) systems or through other wireless monitoring systems that can be installed economically. The technology provides capabilities to remotely monitor the cathodic protection system's current and "instant-on" and "instant off potentials," allowing allowed continuous monitoring of CP systems from a central location, and provide personnel with immediate warning of potential corrosion hazards. Case studies are presented for three Army Installations and one Air Force Installation, each with different approaches to remote monitoring of cathodic protection systems for potable water storage tanks and buried pipelines. The benefits of implementation of remote monitoring are the cost avoidance of traveling to remote sites to check each rectifier, and the added capability of instant notification of a malfunction in the cathodic protection system, thus increasing the life of the structures being protected.

KEYWORDS: impressed current, cathodic protection, ceramic anodes, remote monitoring, SCADA

INTRODUCTION

Many Military Installations are spread over large areas and have many water storage tanks that use corrosion protection systems known as “cathodic protection (CP)” systems, which protect the internal or “water-side” of the tank. The outer surfaces of underground pipes, such as water, or gas distribution systems, also must be protected from corrosion in the soil using similar CP systems. In either case, CP systems need to be monitored in order to make sure that they are providing enough voltage and current to maintain the cathodic protection.

Impressed current CP systems work by connecting an anode to the structure, and applying a negative potential to the structure and a positive potential to the anode through a current from an external source, controlled by a rectifier. In recent years, ceramic-coated anodes, usually made by depositing mixed metal oxides onto titanium substrates, have been used as an alternative to the silicon-iron and graphite anodes. The ceramic anode makes corrosion protection available at much less than the life cycle cost of previous technologies and in a size-reduction that permits installation in areas previously too small.

Current cathodic protection monitoring procedures require highly skilled engineer/technician personnel and are extremely burdensome for the maintenance staff. These procedures are often deficient, and do not identify all areas where corrosion protection is either inadequate or non-existent. Furthermore, these locations generally increase with time and remain undetected, until structure perforation and failure. (CP) systems for water storage tanks must be periodically tested in order to ensure proper performance.

REMOTE MONITORING TECHNOLOGY

Remote monitoring technology^{1,2,3,4} allows “on-demand” monitoring of CP systems: (1) from a central location, such as the Office of the Chief of Operations & Maintenance (O&M), or (2) from out in the field by simply driving within 1,000 feet of the CP monitoring station for a given cathodically protected structure, whereupon the CP system status information is instantly up-loaded into a portable computer or personal digital assistant (PDA), and will provide personnel with immediate warning of potential corrosion hazards.

Historically remote monitoring of cathodic protection levels has undergone several evolutions. In the 1980’s a system using ground transmitters and receivers placed in aircraft that routinely flew over the pipeline for inspections was promoted. The fly-by system proved uneconomical and ineffective due to communications frequency issues, low transmitter power, and the cost of the monitoring hardware. The remote monitoring systems in use today are: (1) cellular telephone based systems, (2) Supervisory Control and Data Acquisition (SCADA) based systems, and (3) “drive-by” remote monitoring units. These remote monitoring systems both greatly increase the accuracy, frequency, and number of monitoring locations to assure that complete protection is maintained on all the protected structures. Remote monitoring systems also automate the data storage and analysis to identify any areas needing remediation and repair before any significant corrosion occurs.

CASE STUDIES

Case Study 1: Cell Phone Based Remote Monitoring at Army Installation #1

Remote monitoring units (RMUs) installed on two elevated water storage tanks at a large Army Installation in the Southwest. They are identified as Structure #1- 1.5 MMG Elevated Water Tank, and Structure #2- 2.0 MMG Elevated Water Tank. It was anticipated that any Pentium based system with at least 64 Mbytes of RAM, 5 Gigabytes of unused hard drive capacity, 56K modem directly accessing commercial telephone lines and using Microsoft's Windows 95, 98, NT or 2000 would be sufficient (later to include Windows XP) for the projects needs. Each of the two water tank sites was visited and basic data gathered regarding the cathodic protection system operating parameters. These data are shown in Tables 1 and 2. It should be noted that although the cathodic protection system on the Tank #2 was behaving somewhat erratically, it appeared to be providing effective corrosion protection to the tank.

Based on the photos and site inspection, it was determined that the RMU for the Tank #1 could be installed directly on or adjacent to the CP Rectifier unit mounted on the tank support leg, while the other RMU for the tank #2 would be mounted either inside on the exterior of the equipment building in which the CP rectifier was installed at the RMU contractors preference. (See Figures 1a and 1b). Two prospective manufacturers were identified as having relatively inexpensive RMUs (less than \$1000/RMU equipment cost) with the desired operating parameters. These parameters are shown in Table 3.

TABLE 1. CATHODIC PROTECTION SYSTEM BASIC DATA FOR WATER TANK #1

Structure 1	1.5 MMG Elevated Water Storage Tank	
AC Input	120V/60Hz/1phase - 3.37A	
DC Volts Max.	30	
DC Amps Max.	8	
Current Output Shunt Rating	100 mV = 10 Amperes	
Operating Data	Rectifier Meter	Test Meter
Volts:	2.1	2.149
Amps:	0.15	1.5 mV where 10 mV = 1 Amp
IR Free Potential (mV):	-980	-980
Potential Set Point (mV)	-980	
"On" Potential (mV):		-1151
Note: This unit is a single circuit unit with no separate riser protection circuit		

TABLE 2. CATHODIC PROTECTION SYSTEM BASIC DATA FOR WATER TANK #2

Structure 2:	2.0 MMG Elevated Water Storage Tank	
AC Input	120V/60Hz/1phase - 3.37A	
DC Volts Max.	30	
DC Amps Max.	8	
Current Output Shunt Rating	100 mV = 10 Amperes	
Operating Data	Rectifier Meter	Test Meter
Volts:	1.8 - 1.9	2.149
Amps:	0.02 - 0.03	0.0 mV where 10 mV = 1 Amp
IR Free Potential (mV):	varied -969 to -987	-980
Potential Set Point (mV)	-978	
"On" Potential (mV):		-1028
Note: This unit has a rheostat controlled secondary output circuit to protect the riser pipe		



FIGURE 1a- Elevated 2 MMG potable water storage tank at Army Installation #1



FIGURE 1b- Typical RMU installed on water storage tanks at Army Installation #1

TABLE 3. RMU OPERATING PARAMETERS

Characteristic	Description of Requirement
No. of Data Monitoring Channels	2
Ampere Monitor	mV drop across rectifier current shunt with resolution of 0.1 millivolt and minimum RMU channel input impedance of 1 megohm.
Voltage Monitor	Voltage at output terminals of Rectifier with resolution of 0.1 volts and minimum RMU channel input impedance of 1 megohm.
Structure to Electrolyte Potential	Ability to measure both "On" and "Instant Off" potentials using existing permanently installed reference electrode with resolution of 1 millivolt and minimum RMU channel input impedance of 10 megohm.
Options	With 2 monitoring channels, choice would have to be made as to whether (1) system voltage and amperage would be monitored or (2) system amperage and structure to electrolyte potential would be monitored
Installation requirements	System would have to be furnished and installed complete by the same supplier.

The RMU chosen for installation communicated by cell phone modems with 2 channels of data acquisition plus the control channel. It was considered preferable to be able to measure all three parameters of CP system operating voltage, current and potential (both "On" and "Instant-Off"). The cell-phone based RMU hardware and its software were installed and commissioned at Tanks #1 and Tank #2. It took over 6 hours to complete the first installation (including gaining familiarity with local telephone communications requirements), but only 3 hours to complete the second installations and even less time for the software installation including setting parameters for site identification, data acquisition, values to be measured and alarm limits for each channel.

Data accuracy was determined by simultaneously acquiring data using the RMUs and personnel at each site using a precision voltmeter at each site to measure the same data. As can be seen from the data in Table 4, the accuracy of the system during the initial field tests was extremely good and well within the 2% accuracy limits set by the specifications. It should be noted that there were some communication problems with the Tank #2. This occurred due to problems with the telephone company and were immediately resolved by re-setting the RMU at the site. The ability to "log" data on a continuing "real time" basis was also demonstrated

TABLE 4. RESULTS OF POST-INSTALLATION RMU TESTING

Site	Parameter	Voltmeter Value	RMU Value
Tank1	Current (in	0.28 - .30	0.28 - 0.29

	amperes		
Tank 1	Potential "On" (in -mV)	1.140 – 1.145	1.140 – 1.140
Tank 1	Potential "Instant Off" (in -mV)	0.970 – 0.980	0.960 – 0.980
Tank 2	Current (in amperes)	0.04 - 0.04	0.04 – 0.04
Tank 2	Potential "On" (in -mV)	1.063 – 1.097	1.050 – 1.145
Tank 2	Potential "Instant Off" (in -mV)	0.970 – 0.980	0.960 – 0.980

Case Study 2: SCADA Based Remote Monitoring System at Air Force Installation

Many military Installations use Supervisory Control and Data Acquisition (SCADA) systems (5) to monitor water levels in potable water storage tanks and to monitor the performance parameters of sewage lift stations.⁵ The SCADA system is wireless; it transmits its data to a central control and monitoring station and receives control signals via radio frequency transmission. Control information for the water pumps and sewage lifts station can also be transmitted to the equipment from a central location through the SCADA.

One U. S. Air Force Base in the Southeast is already monitoring impressed current cathodic protection (ICCP) systems on 4 of 5 elevated water potable storage tanks using their existing Supervisory Control and Data Acquisition (SCADA) system. By installing 3 new deep well anode beds, the number of rectifiers in the CP system for underground pipes will be reduced from 40 to 20. The AFB existing SCADA system will be extended by installing 20 additional SCADA transmitting stations at a cost of \$10,000 each, at the locations where the 20 additional rectifiers will be installed and they will be interfaced to SCADA units. The SCADA system will transmit the CP data to a central location upon request. The SCADA also provides control of the rectifiers, from a central location at any given time.

The staff has utilized the services of their SCADA system sole source supplier to implement the first CP monitor system at their base on an elevated water storage tank. A schematic diagram of the SCADA based system is shown in Fig. 2a-d. This system can automatically read the rectifier voltage, amperage and the structure potential at the SCADA location. The SCADA Transmitter broadcasts line of site to an antenna on top of a water tower. The signal is re-broadcast to the main SCADA system and then can be stored in and displayed on computers in maintenance staff offices.

A typical SCADA system and cathodic protection system rectifier are shown in Figures 3a and 3b. The rectifier fine control taps are serviced by relays on the SCADA control board, which allow fine voltage control. The rectifier potentials are read directly from the rectifier into the SCADA electronic board. Also, a Hall Effect device (Figure 3b) provides rectifier current readings to the SCADA. From this "proof of concept" system, the Air Force Base has successfully replicated the first system at 3 other water tank locations

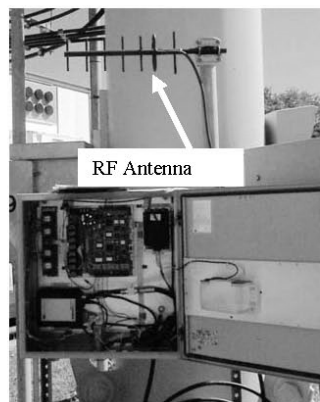


FIGURE. 3a- SCADA system to which CP data acquisition system is interfaced at a USAF Base. Note antenna for wireless transmission of data.



FIGURE 3b- Typical rectifier for CP system installed on elevated water storage tanks at USAF Base

CP data will be stored in the Air Force's Geographical Information System (GIS) database and be accessible through standard USAF GeoBase software. The SCADA system will allow condition based display of data at a central location to allow for graphical display of any CP problems within the GIS. For example, a point with questionable readings could be made to display the problem in yellow or red indications. Analysis software in the GIS will provide the capability to visualize any utility infrastructure endangered by a failure of the CP system. For example, a user could click on a "bad" point and see a display highlighting portions of the utility infrastructure at risk, along with an explanation of system maintenance needs.

The cost of implementation of the SCADA based CP monitoring/control system is very different for locations where existing SCADA already exists versus those locations where such is not the case. For example, at their water storage sites, this AF Base already has a SCADA to control the water level in each tank and to turn various pumps on and off. However, it will cost \$10,000 per location to install the SCADA at locations where it does not currently exist.

The only method the USAF Base has for monitoring test stations is by hard wiring the test station leads back to the nearest SCADA system. They have acknowledged that currently, this limits them to measuring only test points within a few hundred feet of the SCADA system. They have also expressed concerns that with the fact that these systems are limited to line of site radio frequency (RF) transmissions, and that in some cases the RF signals are attenuated by leaves on trees during the summer, in which case no CP data can be transmitted.

Case Study 3: Drive by Remote Monitoring Units at Army Installation 2 and Army Installation 3

Army Installation 2. At a second Army Installation, impressed current cathodic protection (ICCP) rectifiers and groundbeds were installed on one natural gas main, one steam main, one water storage

reservoir, and three separate water supply mains. Selection of sites for ICCP installations included input by the Directorate of Public Works staff. This project demonstrated and implemented 6 deep anode impressed current cathodic protection systems (ICCP), 106 drive-by type remote monitoring units (TSDMU) for existing test stations, and 26 drive-by type remote monitoring units (RDMU) (See Figure 4) for existing and new rectifiers. Also, impressed current CP rectifiers and groundbeds were installed on one natural gas main, one steam main, one water storage reservoir, and three separate water supply mains. The six new rectifiers and deep anodes are capable of providing their full rated current output of 30 Amperes DC.

Based on the results of problems with cell phones and expense of installing the SCADA systems, the “drive-by” remote monitoring units (RMU) were installed at Army Installation 2. They were buried in the ground at about 200 impressed current CP monitoring stations. The units were programmed to “wake up” once a month, whereupon they transmit CP data using a low power RF signal. During the time window that the drive-by RMUs are transmitting, CP system maintenance personnel drive by within 0.1 mile of the remote monitoring points, guided by a global positioning system (GPS) map displayed on a laptop or PDA. Since each RMU is tied into the GPS, it broadcasts its location along with its data to the PDA. Once back in the office, the operator can download the data into a computer where the CP files are stored and further trending analysis can be performed.⁶

The contractor who maintains the ICCP systems said that previously it would take him 2 months to obtain readings from the 106 ICCP test stations and 26 rectifiers that supply the cathodic protection current for necessary corrosion protection of those utilities. Now he can accomplish the same task in 2 days, with automated data saved in a format that allows him to establish trends for early signs that there may be a problem with the system that needs immediate attention.

Army Installation 3. At a third Army Installation, a similar drive-by remote monitoring system was implemented for a new state-of-the art ICCP system on natural gas piping, which included the use of a self-monitoring, self regulating constant output DC power supply energizing ceramic tubular shaped energy emitters (commonly referred to as cathodic protection anodes) buried deep into the earth (deep anode beds). In addition, the drive-by remote monitoring units were implemented for an ICCP system installed in a new 2 million gallon elevated water storage tank, which is this Installation’s only source of potable water.

The battery operated remote monitoring system uses 10 – 15 year life replaceable batteries. Installation maintenance personnel drive through the Installation once a month with a standard PC portable computer connected to a small radio transmitter/receiver with a magnetic antenna temporarily mounted on a pickup truck roof (See Figure 5). A GPS unit monitors both the vehicle location and shows all 106 monitoring points distributed around the base on map displayed on the PC screen. Six of these monitor locations measure the output of the six DC power supplies used to energize the ICCP systems, while the other 100 units monitor the corrosion control effectiveness at key locations throughout our buried gas piping system throughout the installation. It is anticipated that it will take as little as 2 hr. to accomplish the entire ICCP survey, compared to the 5-10 days that it would take for a trained technician’s time to do the same work. As an additional benefit, the data is then automatically transferred in to an Excel spreadsheet where it is automatically analyzed on a “pass/fail” basis.

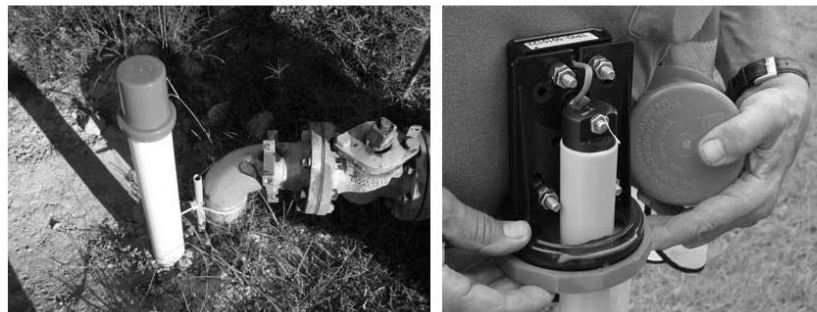


FIGURE 4- Left: Typical Pipe Protection Remote Monitoring Units Installed to Interrogate the Pipeline and Transmit System Corrosion Control Effectiveness Data. Right: Remote Monitor Unit with Cap Removed Showing Terminal Connection Points



FIGURE 5- Army Installation personnel can use laptop PC to automatically interrogate and record CP protection levels while being driven by each monitoring station

At both of these installations, for the rectifier sites where no existing SCADA exists (e.g. at rectifier units protecting piping, well casings, etc.), the SCADA would have to be installed first which had an estimated cost of \$10,000 per location. This makes the system uneconomic at this Army Installation. As the CP systems only require monitoring once a month at Army Installations #2 and 3, it has been confirmed that personnel can obtain data for the same number of points at a cost of less than \$12,000 annually.

Given that these Army Installation have more than 100 monitoring points where no existing SCADA is located (and where none is anticipated to be required for other measurement purposes), the “drive by” system is currently the only economically justifiable system available for automating the data acquisition and recording process

In some cases, direct burying of CP Test Station and monitor unit with 15 year nominal battery life at select locations is possible to prevent damage by normal grounds maintenance work particularly including lawn mowing work. These locations would be “marked” by easily locatable “magnetic” sensors. Implementation of “Drive by” Test Stations that can automatically acquire and transmit both “On” and “Instant-Off” potentials without interrupting impressed current CP system rectifier(s). A further development may allow the measuring of polarization decay where the -850 mV potential criteria is not being satisfied (this is under current development but may or may not be ready during the time of this project implementation, and would not require any new hardware (only software download into CP system test station units).

COMPARISON OF WIRELESS CORROSION MONITORING TECHNOLOGIES

Hardwired RMUs for CP systems require running miles of wiring between the central control system to each monitoring station, and are not practical for military installations. In cases where the SCADA system is not a viable option, cell phone based RMU systems are best used when it is not practical or cost effective to use drive by systems, or when the data must be taken more often than once a month. For example, a remote location many miles away from the central monitoring station would constitute a hardship for maintenance personnel to drive by the location to acquire data. Of course, in order to use the cell phones, it must be established that the cell phone signals for these systems are highly reliable in those locations.

Satellite based systems provide another alternative. They can usually provide CP data readings anywhere and at anytime through the internet. Their initial cost is only about \$500-\$700 per location, but the data cost per reading per location is generally \$5-\$10. For a large number of locations to be monitored, this fee could become rather expensive. Also, the satellite based systems are limited to line of site. If a small number of remote locations are to be monitored, the satellite-based monitoring systems may be suitable, however, if a very large number of locations need monitoring, the satellite monitoring system may not be cost effective. A comparison of the attributes of each system is presented in Table 5.

TABLE 5. COMPARISON OF REMOTE MONITORING TECHNOLOGIES

	SCADA-Based System	Drive-by System	Cell phone-Based System	Satellite Based System
Initial Cost	\$10,000 per monitoring station	\$2,000 per monitoring station	\$2,000 per monitoring station	\$500-700 per station
Maintenance Requirements	Moderate	Low	Low	Very low
Complexity	High	Low	Low	High
Advantages	<ul style="list-style-type: none"> -Takes advantage of existing wireless system -can take readings at any time -can control 	<ul style="list-style-type: none"> -Low installation cost - can easily be installed - broadcast frequencies are 	<ul style="list-style-type: none"> -Low installation cost - can easily be installed - can take readings at any time 	<ul style="list-style-type: none"> -Monitor CP system virtually anytime, anywhere in the world through the internet

	remotely from a central location at any time -can interface with GIS system	pre-approved	- broadcast frequencies are pre-approved - can control remotely any location at any time	
Disadvantages	High cost -Signal path must be properly planned for adequate transmission Signals must be line of site (LOS) -Signals are sometimes lost if there are impediments to LOS - FCC approval is needed for new SCADA frequencies	-Can not monitor from central location; must drive by within 0.1 mile of monitoring station	-Cost of cell phone services -Cell phone signals are sometimes lost in certain locations	-Charges fee/reading/location -Line of site limitations
Recommendation	-Use where existing SCADA system is available, such as water tanks -Do not install additional SCADA systems	-Use where there are no existing SCADA systems -Use when drive by systems are viable	Use where there are no existing SCADA systems -Use where drive by systems would not be viable-very remote areas	Use where there are no existing SCADA systems -Use where drive by systems would not be viable-very remote areas

CONCLUSIONS

The benefits of implementation of the RMUs along with upgrade of CP systems are the cost avoidance of traveling to remote sites to check each rectifier and test station, and the added capability of instant notification of a malfunction in the cathodic protection system. If SCADA systems are already available where the RMUs are to be installed, then the CP monitoring systems should be interfaced to the SCADA system. If the SCADA system is not readily available, either cell phone-based systems, satellite downlinked data systems, or drive-by systems should be implemented. The choice of whether to use cell phones based systems or drive-by systems depends on the reliability of the cell phone signals at those particular locations. By implementing remote monitoring for cathodic protection and ceramic anode-based impressed current cathodic protection systems, the life of the tank, water distribution, or gas system is expected to be extended by 30 years, while reducing the work load of Installation maintenance personnel.

Based on the results of these projects, recommendations are being provided for revisions to Unified Facilities Guide Specifications (UFGS) 13111A "Cathodic Protection System (Steel Water Tanks)" and

UFGS 13112A "Cathodic Protection System (Impressed Current)." These revisions include the specifications and instructions for installing the advanced impressed current cathodic protection systems in conjunction with the "drive-by" remote monitoring units for cathodic protection systems.

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2. Vicki L Van Blaricum, Jack T. Flood, Michael J. Szeliga, and James B. Bushman , Demonstration of Remote Monitoring Technology for Cathodic Protection Systems: Phase II , ERDC/CERL Report Number 98/82 (1998).
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5. "Harnessing SCADA Without Undermining Security," Journal of the American Water Works Association (AWWA), July 2004.
6. A. Kumar, L. D. Stephenson, and J. Bushman, "Remote Monitoring of Cathodic Protection and Cathodic Protection Upgrades for Tanks and Pipelines," ERDC/CERL TR-07-25, U. S. Army Corps of Engineers, Engineer Research and Development Center, Construction Engineering Research Laboratory, Champaign, IL (2007).

Appendix B: Rectifier Operating Manuals

Deep anode bed application

C.P. SENTINEL AUTOMATIC TYPE CATHODIC PROTECTION RECTIFIER

INSTALLATION, OPERATION, & MAINTENANCE MANUAL

SINGLE PHASE INPUT

MODEL:

CC – CURRENT CONTROL

CV – VOLTAGE CONTROL



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Rev. 2.0, April, 2005
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APPENDIX:

INCLUDES ELECTRICAL SCHEMATIC, RECTIFIER DATA SHEET, AND ANY
OTHER OPTIONAL INFORMATION

C.P. SENTINEL AUTOMATIC CURRENT-VOLTAGE CATHODIC PROTECTION RECTIFIER MANUAL
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INTRODUCTION

Corrosion of underground structures (pipelines, well casings, etc.) is a process that occurs every minute of every day. As such, continuous protection is required to effectively prevent damage that could cost a company significantly in lost revenues, manpower, and equipment. The proper selection, installation, and operation of a suitable corrosion prevention system can be crucial to ensure that this costly damage does not occur. For well-coated structures, structures with small surface areas, or where minimal Cathodic Protection is required, a "sacrificial" type corrosion prevention system may be used. For poorly coated structures, structures with large surface areas, or where a larger amount of Cathodic Protection is required, an "impressed current" type corrosion prevention system is required. One key component of an impressed current corrosion protection system is a Cathodic Protection rectifier. A rectifier is a device that is used to convert "alternating current" (AC), as provided by the power utility, to "direct current" (DC), as is required for Cathodic Protection. The rectifier should be selected based on the type of control required for the specific application, the amount of Cathodic Protection required to provide effective protection, and the reliability of operation in the subject environment. **IRT Integrated Rectifier Technologies, Inc.** manufactures Cathodic Protection rectifiers that exceed industry standards for superior corrosion prevention and, as such, an IRT rectifier unit is a smart investment for any company.

IRT Integrated Rectifier Technologies, Inc. Cathodic Protection rectifiers and associated products are designed by a knowledgeable engineering team with years of experience in the corrosion field and manufactured by skilled technicians with a dedication to quality. The IRT units are designed with superior components to provide a high quality, reliable rectifier with an economic cost for your application. IRT maintains a large volume of in-stock components and sub-assemblies to ensure that orders can be shipped to you in the shortest time frame possible.

IRT products are sold and serviced by leading corrosion prevention engineering companies throughout North America and Internationally. These companies have superior expertise in the corrosion industry and have the personnel to meet all of your corrosion prevention system requirements including design, installation, and maintenance. IRT products are also available through leading material supply companies throughout North America.

Rectifiers manufactured by **IRT Integrated Rectifier Technologies, Inc.** are guaranteed against defects in design, workmanship, or material for a period of one year from the time of shipment from our facility. Please refer to our warranty statement for further details.

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DELIVERY INSPECTION

Although the rectifier unit may not be scheduled for immediate installation, we recommend that it be thoroughly inspected, both externally and internally, upon receipt to ensure that no damage has occurred during shipment. Please remember that although the outside of the rectifier packaging may not show any signs of damage, there may be internal damage that will not be apparent until the outer packaging is removed. Any damage, whether internal or external, must be reported to the freight carrier immediately. If any damage has occurred during shipment, an indication of this should be made on the freight paperwork, the shipment should then be accepted, and a claim filed with the freight carrier. Please ensure to retain the original packaging that may indicate how the damage occurred.

If damage has occurred during shipment and repairs or a return to the factory is required, please contact us, or your local IRT distributor, with the Serial Number and the Model Number of the rectifier. This information is crucial for us to determine the rectifier unit in question and to be able to provide suitable assistance. A Return Materials Authorization (RMA) number must be obtained from the factory prior to return of any damaged rectifier units.

PRE-INSTALLATION STORAGE

If the rectifier unit is to be stored prior to installation, it is recommended that it be stored in a dry area, preferably indoors. If the unit is to be stored outdoors for an extended period of time, it is recommended that it be placed on a raised surface (pallet or platform) and covered with a protective sheet or tarp to ensure the packaging does not deteriorate due to rain or snow. Whether stored indoors or outdoors, the unit should be placed in an area where it is protected from accidental damage from moving vehicles or equipment. Ensure that the rectifier unit is transferred to and from the storage facility using proper handling techniques.

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SAFETY PRACTICES

This symbol denotes a possible shock or electrical hazard.

**DO NOT INSTALL, REMOVE, or REWIRE
THIS EQUIPMENT WITH POWER APPLIED!!**



As Cathodic Protection rectifiers are connected to the AC utility power, electrical shock hazards are present within the rectifier units. It is recommended that only qualified electronic or electrical personnel operate and maintain these units and that those personnel familiarize themselves with the areas of possible hazard within the unit. Following these practices can enhance the safety of personnel.

- 1.) Prior to site maintenance or inspection, familiarize yourself with the rectifier and conditions at the site.
- 2.) Prior to doing any maintenance or troubleshooting on a rectifier unit, familiarize yourself with any possible hazard points within the unit by reviewing the electrical schematic and the physical layout of the rectifier.
- 3.) Whenever possible, set the AC disconnect from the power utility to the "OFF" position prior to starting any work on the rectifier unit. Even with the rectifier AC input circuit breaker in the "OFF" position, hazardous voltages are still present at any terminals connected to the rectifier AC input terminals. Always tag and lock out the disconnect to ensure others do not energize it while you are completing the rectifier work.
- 4.) Prior to opening the rectifier enclosure door, lightly touch the back of your hand to the enclosure latch. If you feel an electrical tingle, set the fused AC disconnect to the "OFF" position and contact an electrician for assistance.
- 5.) When taking readings across the rectifier terminals, it is recommended to use only one hand, if possible.

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GENERAL INSTALLATION RECOMMENDATIONS

To ensure reliable, long-term operation of the Cathodic Protection rectifier, proper installation of the unit is required. Though most installation sites differ, there are several key guidelines that should be followed.

- a) Prior to installation, check the connections (especially the electrical connections) on the rectifier unit to ensure that nothing has become loose during shipment. It is also recommended that if any scratches occur to the enclosure during installation, that these points be touched-up to prevent corrosion on the enclosure.
- b) Selecting the site of installation is a very important factor. The rectifier should be installed in a location that is easily accessible by company personnel for regular adjustment, monitoring, and maintenance. However, it should not be located in areas where unauthorized personnel have easy access to the unit and may damage or vandalize it (i.e. residential areas, playgrounds, farm yards, etc.). The convenient access to AC power and the cathodic protection DC connections must also be considered when choosing the rectifier location.
- c) Proper ventilation and cooling of the rectifier unit is essential and must be considered when choosing a suitable location. Air-cooled rectifiers are cooled by the natural convection of cool air drawn into the bottom of the rectifier enclosure, passing over the internal components, and the resultant warm air expelled from the top or sides of the enclosure. Oil-cooled rectifiers are cooled by the natural circulation of oil from the bottom to the top of the rectifier tank, over the internal components, and the resultant heat is radiated from the upper walls of the rectifier tank. As such, when choosing the installation site for the rectifier, adequate spacing should be allowed for around the sides of the rectifier unit. The rectifier should not be located near sources of heat such as exhaust vents, power generators, etc. If possible, place the rectifier unit in an area where it will be shaded during the hottest part of the day. If the rectifier is to be installed in an area with a high ambient temperature and minimal natural shading, a protective sunshade is recommended.
- d) The rectifier unit should be mounted on a secure surface. Ensure that the wall, pole, frame, or mounting pad is designed to hold the full weight of the rectifier unit.
- e) If the rectifier is to be installed in an area subject to frequent lightning activity, upgraded, high-energy type surge arrestors are recommended. If possible, do not locate the rectifier on a hill top where there increased chances of lightning strikes. Use of a low resistance ground rod(s) is recommended. Locate the ground rods adjacent to, but away from the rectifier, the ground bed, and incoming CP cables. Remember, most damaging voltage surges are the result of induced pickup rather than a direct strike.
- f) Do not install other equipment on or inside the rectifier enclosure without prior consent from the factory. Unauthorized equipment installation will invalidate the rectifier Warranty, as IRT has no control of the equipment added or the resultant detrimental affect to proper rectifier cooling / operation.

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RECTIFIER CONNECTIONS AT SITE

DO NOT INSTALL, REMOVE, or REWIRE THIS EQUIPMENT WITH POWER APPLIED!!



After the rectifier has been installed in a suitable location, have a qualified electrician connect the rectifier unit to the AC supply following local and national codes. Please note that most electrical codes require a disconnect device between the AC power supply and the rectifier. Ensure that for dual AC input rectifiers (115 / 230 or 230 / 460 VAC), that the AC input terminal jumpers are properly configured for the actual AC input voltage being supplied and that the AC input wires are connected to the correct AC input terminals.

The grounding rod(s) should be connected to the ground lug terminal adjacent to the AC input terminals within the rectifier.

Next, connect the cable(s) from the anode bed to the RECTIFIER POSITIVE output lug terminal(s) and the structure cable(s) to the RECTIFIER NEGATIVE output lug terminal(s). Ensure that these cables are suitably sized for the expected current and the length of the cable run. Also, it is absolutely imperative that the polarity of DC connections is correct. A reversal of the DC cables can actually cause accelerated corrosion and eventually, severe damage to the structure to be protected.

RECTIFIER OPERATION MODES

C.P. SENTINEL AUTOMATIC CURRENT/VOLTAGE Rectifiers are capable of the following modes of operation:

CONSTANT VOLTAGE MODE: In this mode the rectifier control circuitry automatically adjusts the rectifier output to maintain the VOLTAGE at the preset level. In this mode, the Current Set potentiometer determines the current limit. When operating in this mode and maintaining the VOLTAGE set point, the RED LED is illuminated.

CONSTANT CURRENT MODE:

In this mode the Rectifier control circuitry automatically adjusts the rectifier output to maintain the CURRENT at the preset level. In this mode, the Voltage Set potentiometer determines the voltage limit. When operating in this mode and maintaining the CURRENT set point, the GREEN LED is illuminated.

MANUAL MODE: (OPTIONAL)

Rectifiers equipped with this option are supplied with a conventional manual tap-adjusted transformer in addition to the automatic control circuitry. This mode permits the operator to control the rectifier output by gating 'on' the Silicon Controlled Rectifiers to conduct as conventional diodes. Manual rectifier output control is achieved by switching the Automatic-Manual Switch to the Manual mode position and then adjusting the transformer secondary taps.

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THE VI-SENTRY CONTROLLER

C.P. SENTINEL AUTOMATIC CURRENT/VOLTAGE Rectifiers are controlled by the IRT **VI-SENTRY** Controller. Refer to the following layout of the **VI-SENTRY** Controller for location of controls and jumpers:

NOTE:

This section will describe the Controls, Jumpers, Test Points and Adjustments of interest for field setup and operation, as performed by QUALIFIED TECHNICAL PERSONNEL. All Remaining Factory Settings & Calibrations SHOULD NOT be attempted or tampered with.

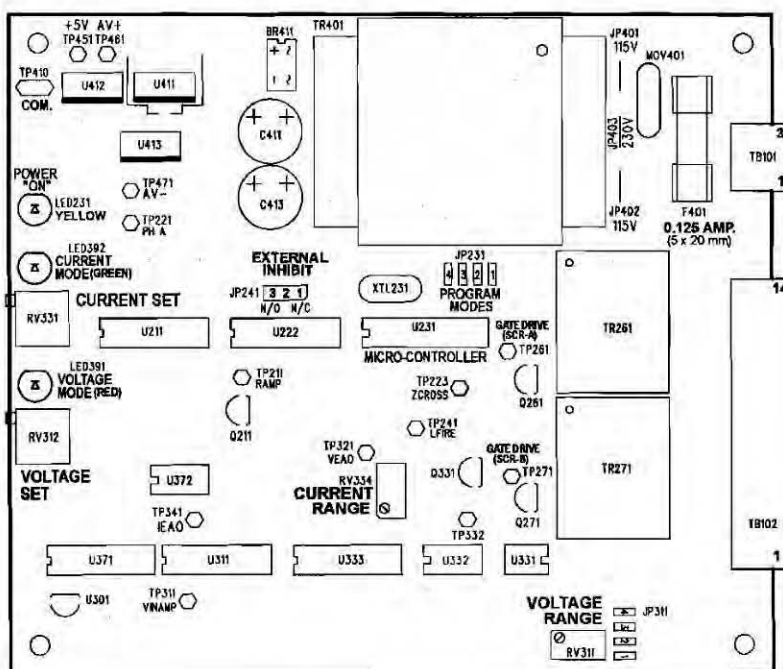


FIGURE 1.0 VI-SENTRY CONTROLLER

**C.P. SENTINEL AUTOMATIC CURRENT-VOLTAGE CATHODIC PROTECTION RECTIFIER MANUAL
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CONTROLS:

Voltage and Current settings are adjusted via two potentiometers available on the **VI-SENTRY** Controller. These potentiometers are 20-Turn trim-pots located at the end of the controller board opposite the wiring connectors. (Refer to Figure 1.0, Page 8).

VOLTAGE: Rectifier output voltage (or Voltage Limit) is set by potentiometer "**RV312**". Rectifier operation in Voltage Mode or Voltage Limit will be indicated by the Red LED "**LED391**", adjacent the Voltage Set Potentiometer.

CURRENT: Rectifier output current (or Current Limit) is set by potentiometer "**RV331**". Rectifier operation in Current Mode or Current Limit will be indicated by the Green LED "**LED392**", adjacent the Current Set Potentiometer.

NOTE:

Depending upon the model and/or configuration of the rectifier ordered, one or more of these potentiometers may be mounted external of the controller board on the rectifier instrument panel. Consult your Rectifier Specification Sheet.

CAUTION!!

Do NOT attempt to alter the settings of any other trim pots on the controller board. These are factory calibrations and tampering with these settings could jeopardize proper operation and scaling of the **VI-SENTRY** Controller.

JUMPER SETTINGS:

The **VI-SENTRY** Controller is designed to adapt and accommodate a wide variety of field installations and control situations. To make this accommodation easier, please review the following Jumper functions and settings:

A. INPUT VOLTAGE SELECTION (JP401, JP402, & JP403)

INPUT VOLTAGE	JP401	JP402	JP403	COMMENT
115 VAC	INSTALLED	INSTALLED	OMITTED	DEFAULT POSITION
230VAC	OMITTED	OMITTED	INSTALLED	OPTIONAL POSITION

B. SCR GATE DRIVE PROGRAM MODES (JP231)

"JP231" SETTING	FUNCTION	COMMENT
JP231 – 1	Increases number of gate pulses to 10	INSTALLED
JP231 – 2	NOT USED	OMITTED
JP231 – 3	Doubles SCR Gating "ON" & "OFF" times	INSTALLED
JP231 – 4	Doubles SCR Gating "OFF" time	OPTIONAL

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C: EXTERNAL INTERRUPT (JP241)

"JP241" SETTING	FUNCTION
JP241 PINS 1 - 2	Normally Closed contacts = Rectifier output current
JP241 PINS 2 - 3	Normally Open contacts = Rectifier output current (Default Setting)

D: VOLTAGE RANGE SETTINGS: "JPR311"

Header "JPR411" is factory set to determine the available output range of voltage control.

OTHER CONTROLLER PARTS & FUNCTIONS

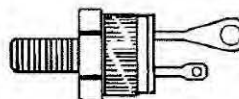
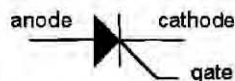
FUSE: "F401" is located on the circuit board near the control transformer. This is a 0.125 ampere, slow-blow type of 5mm x 20mm metric style fuse. Replace with same fuse type.

POWER ON LED: Controller "POWER ON" operation is indicated by "LED231", Yellow

WIRING CONNECTORS: "TB101" & "TB102". These are 3-pin & 14-pin plug on connectors, respectively. Ensure all wiring connections are secure by tightening the screw terminals on these connectors.

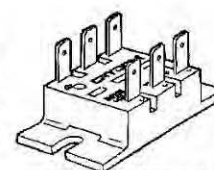
THE SILICON CONTROLLED RECTIFIER (SCR)

Automatically controlled rectifiers utilize phase control of the supplied 50 or 60 Hertz AC voltage using a solid-state device called a Silicon Controlled Rectifier (SCR). This device is similar to a conventional diode, but is equipped with an extra terminal for control called the GATE. Although akin to a diode, this device has unique properties of being able to block conduction of current when the device is forward biased until an appropriate signal is applied to the Gate terminal. Once the appropriate gate signal is applied, the SCR remains in conduction while forward biased, or until the current through the device goes to almost zero.



The control of the rectifier DC output is accomplished by "gating on" the SCR at the point in the AC waveform necessary to produce the desired output. This output can be the regulated DC Voltage, the DC Current, the Structure to Reference Electrode Potential or a combination of the three modes of control. A minimum of two SCR's are required to achieve full control over the AC waveform. The two SCR's are configured with two diodes into a full-wave bridge configuration.

Often SCR's and diodes are combined into full-wave controlled rectification modules. Typically the modules used are comprised of two SCR's and two diodes with the cathodes of the 2 SCR's connected to the module Positive (+) terminal. SCR-Diode modules are then mounted to a suitably sized heatsink for cooling.



SCR-DIODE MODULE

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GENERAL COMPONENT DESCRIPTION

When operating any equipment, it is a good practice to become familiar with the key components and the general operation of that piece of equipment. The following is a summary of the key components of a rectifier and their function:

The **AC Input Surge Arrestor** is a device that protects the rectifier components from voltage surges that may occur across the AC input of the rectifier. It does this by providing a bypass circuit for the resultant current from these high voltage surges after a specific voltage threshold has been reached. Most surge arrestors are designed to handle a certain number or energy value of surges prior to failing.

The rectifier **AC Input Circuit Breaker (CB1)** is a fully magnetic type that serves three key functions. It is used as an "OFF-ON" switch for the rectifier, it provides "short circuit" protection, and, to a lesser degree, provides input overload protection.

The rectifier **Main Transformer (T1)** provides full electrical isolation between the utility AC power and the Cathodic Protection DC circuit. It also steps the voltage up or down as required for the DC circuit and, for tap type units, provides a means of output adjustment.

The rectifier **AC Secondary Fuse** is a time lag or slow-blow type that provides protection from not only short-circuits or overloads in the DC output circuit but also in the diode bridge circuit.

The rectifier **SCR-Diode Bridge Assembly** is comprised of silicon controlled diodes (SCR's) and diodes configured into a full-wave bridge configuration. The SCR-diodes are supplied with suitably sized heatsinks to ensure that the SCR-diodes do not exceed 100°C at full rated output. The SCR-diode bridge controls and rectifies the AC secondary voltage of the transformer into DC voltage that can be used for Cathodic Protection. This DC voltage level is then automatically maintained by the **VI-SENTRY** Controller in Current or Voltage Mode, as set by the operator.

A **Varistor** is supplied across the AC input to the diode bridge to provide additional protection from any voltage surges that may pass the main AC surge arrestor or be developed by the main transformer. A second varistor may also be supplied across the DC output of the diode bridge at special request.

The **Current Monitoring Shunt** is a block style calibrated resistor with an accuracy of 0.25%. The DC current and voltage rating are stamped into the body of the shunt.

The rectifier **Ammeter & Voltmeter** utilize an analog, taut-band type movement that provides $\pm 2\%$ accuracy. The DC output amperage of the rectifier is monitored by a meter connection across the calibrated test screws of the above shunt. The DC output voltage of the rectifier is monitored by a meter connection across the DC output terminals of the rectifier.

External Interrupt Terminal Block: Two terminals are provided on the front panel of the rectifier for purposes of interrupting the rectifier output using the **VI-SENTRY** Controller. Jumper "JP241" on the controller board as required for Normally Open equals rectifier "ON" or Normally Closed contacts equals "rectifier "ON" as dictated by the interrupter being used. This is the preferred method to interrupt the rectifier by an external means. Special circuitry in the **VI-SENTRY** Controller retains all of the operating parameters for resumption of control parameters after conclusion of an interrupt procedure and will not reset the slow start circuitry.

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The **DC Output Surge Arrestor** is a device that protects the rectifier components from voltage surges that may occur across the DC output of the rectifier. Its operation and characteristics are similar to the AC input surge arrestor.

As many optional features / components are available for our customers, it is not practical for this manual to describe all of the possible options in detail. As such, it is recommended that the rectifier data sheet and the electrical schematic be reviewed in detail to become familiar with any features not detailed in this manual.

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INITIAL ENERGIZATION

After the rectifier has been properly connected to the AC supply and the DC output cables, the rectifier is ready to be energized. Before energizing, always double-check both the AC and DC connections to ensure they are properly connected. Ensure that for dual input rectifiers (115 / 230 or 230 / 460 VAC), the AC input terminal jumpers are properly configured for the actual AC input voltage being supplied and that the AC input wires are connected to the proper terminals. For Current Controlled rectifiers, ensure that the rectifier is at its lowest control setting, by adjusting the "Current Adjust" potentiometer to zero. Use a multi-meter to verify static Reference Electrode – Structure potentials (If installed) and record for later reference.

Place the AC fused disconnect switch to the "ON" position and measure across the rectifier AC input terminals to ensure the voltage present is as expected. Next, place the rectifier AC input circuit breaker also to the "ON" position. The "POWER ON" Yellow LED on the **VI-SENTRY** Controller will illuminate. The **VI-SENTRY** Controller is designed with a "slow start" circuitry to minimize in-rush currents and to prevent the rectifier from starting at full output. This slow start time period will last from 3 – 10 seconds. There will be some deflection on the panel meters, although this deflection may be quite minimal on the Ammeter and Voltmeter. For units with a metering switches, ensure to set this switches to the "ON" position.

For **Constant Current** operation, simply adjust the "Current Adjust" potentiometer to the required current. The GREEN LED will be illuminated; provided the **VI-SENTRY** Controller is not in Voltage Limiting mode (with RED LED illuminated). This current will be read on the rectifier Ammeter. The rectifier ammeter can be verified by measuring the voltage (in Millivolts) across the calibrated test screws of the rectifier shunt (not across the connection bolts). To determine the current through the shunt from the millivolt reading taken, the following formula can be used:

$$\text{DC Current (I)} = \frac{\text{Measured Shunt Voltage (Millivolts)} \times \text{Rated Shunt Current}}{\text{Rated Shunt Voltage (50 Millivolts typical)}}$$

Note: Rated shunt current and voltage values are stamped onto the body of the shunt and are also shown on the rectifier data page.

The ammeter can also be verified with an external DC clamp-on type meter, if available.

For **Constant Voltage** operation, simply adjust the "Voltage Adjust" potentiometer to the required output voltage. The RED LED will be illuminated; provided the **VI-SENTRY** Controller is not in Current Limiting mode (with GREEN LED illuminated). This voltage will be read on the rectifier Voltmeter. The rectifier voltmeter can be verified by measuring the voltage at the rectifier output lugs.

It is recommended that all initial energization readings be recorded for future reference. Useful readings to record are structure potential levels prior to energization, AC input voltage & current, DC output voltage and current, tap or adjustment dial setting, structure potential levels after energization, as well as any observed problems or possible future concerns with the installation, in general.

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Rectifiers equipped with MANUAL MODE Option: Adjustment of rectifiers equipped with this option requires the "Automatic-Manual" selector switch be switched to the "Manual" position. Start the rectifier with the Coarse & Fine taps set to their lowest level (Coarse "A" – Fine "1"). Observe and record if necessary the rectifier output currents and voltage levels, and the polarization level of the Structure being protected. Incrementally, increase the transformer tap settings until either target current or polarization levels are attained. The **VI-SENTRY** Controller is NOT required for manual mode, and may be removed for repair if it is not functioning correctly.

After the structure potential readings have been taken and prior to leaving the site, it is recommended that the DC output connections to the rectifier be rechecked to ensure a secure connection. It is also beneficial to recheck the rectifier to ensure that all air inlet and outlet venting on the enclosure is not obstructed in any manner. The rectifier O&M manual should be securely set in it's holder (for small rectifiers without a manual holder, it is recommended that the manual be kept with the main operator or in the control room of the closest station). Also verify that all holes within the enclosure (other than the venting screens) are suitably plugged (such as unused conduit knockouts). For rectifier units with "OFF-ON" meter switches, ensure that the switch is in the "OFF" position prior to leaving the site.

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REGULAR MAINTENANCE & ADJUSTMENT

The basis for any effective CP system is routine documentation & maintenance. Despite the rectifier maintaining the DC output "automatically", it is recommended that the rectifier be checked and adjusted if necessary at least twice per year. Some local regulatory bodies require a monthly or semi-monthly check to ensure proper protection levels are being maintained. These checks also allow you to ensure that the rectifier has not been damaged. When completing this maintenance and adjustment check, it is recommended that all readings and observations be recorded in the site file. With regular maintenance checks and by maintaining good records, future troubleshooting and repair costs can be reduced.

Prior to arriving at the site for the rectifier maintenance check, it is recommended that the technician review the existing rectifier site file to gain familiarization with the subject rectifier and site conditions. Upon arriving at the rectifier site, a visual check should be completed to determine if any changes have occurred. Things to look for are signs of new underground construction, buildings, pipeline tie-ins, bonds, etc. Prior to adjustment of the rectifier, it is recommended that structure potential readings be taken, to determine the adjustment level required. Even if the potential levels are within the required range, the rectifier should still be checked for proper operation.

When approaching the rectifier, ensure that no items have been placed near the rectifier enclosure in such a manner as to block the venting, either on the bottom or sides. As the vent openings on the rectifier enclosure are screened, there should be no refuse inside from birds or larger insects. However, after opening the door of the enclosure, ensure that there has been no significant accumulation of dirt, snow, or other small debris at the bottom of the enclosure, which may adversely affect proper venting.

DO NOT INSTALL, REMOVE, or REWIRE THIS EQUIPMENT WITH POWER APPLIED!!



Prior to any adjustment of the rectifier, measure and record the "As Found" readings of the rectifier (DC voltage, DC amperage, etc.). Next, set the rectifier circuit breaker and the utility disconnect to the "OFF" position to allow for a detailed rectifier inspection.

At least once a year the rectifier should be inspected for loose electrical connections that could eventually cause damage to the electrical panel, wiring, or rectifier components. If an electrical connection becomes loose, the resistance of the connection increases and causes it to heat up. This additional heat will cause the connection to oxidize and become even higher resistant until a failure occurs. The best way to check for a heated connection is with a temperature probe, however, as these are not typically standard issue for Cathodic field maintenance, the visual inspection method will suffice. First, visually inspect all of the main electrical connections within the rectifier for signs of discoloration on the connection terminal, the electrical panel, or the wire attached to the terminal. Key points to check are the DC output lug terminal connections and the fuse holder connections. If you see a suspect connection, use a wrench or other suitable tools to see if the connection is indeed loose. (Note: Be careful when touching these types of connections with your hand as the temperature of loose high current connections can cause a significant burn.) If you do find a loose connection, it should be secured with suitable tools (make sure to secure both the front and rear of the double-nutted panel connections). If a loose connection has already caused damage to the electrical panel, the panel should be repaired or replaced, as re-tightening a connection on a degraded panel will most likely still lead to a future failure.

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Certain main components within the rectifier should also be inspected for signs of over-heating or other damage.

The main isolation transformer (T1) within the rectifier is designed to operate at a fairly high temperature and thus is usually somewhat discoloured. However, it should not be extremely dark or black. If it is, this could indicate insufficient / blocked venting or a problem within the transformer itself.

The AC primary, AC secondary, and the DC output surge arrestors should be checked to ensure that a significant voltage surge has not damaged them. Signs of damage to an arrestor device are usually visually noticeable by a blackened or cracked housing. Please note however that sometimes the operational status of an arrestor is not discernable visually and requires further checking (see Troubleshooting section).

The rectifier fusing should also be checked for overheating. If the fusing is a bolt-on type (for larger rectifier units), ensure that the fastening studs or bolts are secure on both the front and rear. Many smaller rectifier units utilize the "clip-type" fuse connectors that are very convenient for fuse replacement but are also infamous for becoming loose and oxidizing over time. However, with regular checks and maintenance, problems can be avoided. For this type of connection, if oxidation is apparent, the fuse should be removed and both the fuse and the fuse contact surface of the clips cleaned up with some very fine sand paper or emery cloth (only the oxidation layer should be removed, not the protective coating on the copper). If the fuse clips have lost tension, they should be replaced. If replacements are not immediately available, the clips can be "squeezed" together and should then provide a suitable short-term connection to the fuse. A notation should be made however, in the site inspection form for replacement on the next maintenance check. The connection hardware on each fuse clip should also be checked and re-tightened if necessary.

If, after completing the inspection on the rectifier unit, a problem is found other than just a loose connection, refer to the "Troubleshooting" section of this manual. If no problems have been found, the rectifier can be adjusted to a new DC output setting (if deemed required based on the "as-found" structure potential levels). As per the adjustment procedure indicated in the "Initial Energization" section, adjust the DC output of the rectifier to the level required to provide suitable protection to the structure. If the rectifier is adjusted to or near its maximum rated output, future replacement of the rectifier with a larger unit or the addition of anodes may need to be considered. If the required "target" DC output current from the rectifier varies significantly over the year due to load resistance changes, maintenance checks should be done frequently.

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TROUBLESHOOTING

If a problem is found with the rectifier during the maintenance inspection or reported by the local operator, the following troubleshooting procedure can be followed to determine the cause.

The only way to effectively determine the cause of a failure in any piece of equipment is to conduct a systematic analysis of the function and operation of the key components. For this troubleshooting procedure, we shall review the possible faults that may occur starting from the DC output and working back to the AC input.

CAUTION!!

Please be advised that hazardous voltages are present within the rectifier unit even with the rectifier AC input circuit breaker in the "OFF" position. Extreme care should be observed when taking measurements on the front of the instrument panel or the side AC input panel. Only qualified electronic or electrical technicians should attempt internal troubleshooting of the rectifier. The fused AC disconnect should be set to the "OFF" position prior to any internal rectifier maintenance or repair.

Please refer to the Rectifier Specifications Sheet, Electrical Schematic supplied with each rectifier and to the **VI-SENTRY** Controller layout on Page 8 of this manual for component descriptions and test points. Common rectifier failures can be summarized and corrected as follows:

A. NO RECTIFIER OUTPUT CURRENT: This fault may be caused by any one or more of the following conditions:

- **No AC Present:** Check incoming utility supply for the presence of voltage and that it is correct for the rating of the rectifier. Consult your electrician or electrical utility to correct this problem.
- **Rectifier AC Breaker Tripped:** First: Do a visual inspection as described in the Maintenance & Adjustment section of this manual. Secondly, attempt to reset the breaker and observe rectifier output. If the rectifier fails to function correctly, continue with this troubleshooting procedure.
- **Blown Fuse:** Check all rectifier fuses, including the control fuse located on the **VI-SENTRY** Controller circuit board. Replace as required with the identical type, size and rating as supplied. One spare for each fuse used in the unit is supplied with each rectifier.
- **Check Interrupt Circuit:** It is possible for field attached external interrupter to hold the output "Off". Refer to Page 10, Section "C" and Page 11 "External Interrupt Terminal Block" and correct any possible interrupter setting errors.
- **Improper Settings:** Review the settings on the **VI-SENTRY** Controller for Voltage, Current. Any one of these potentiometers set to "zero" will result in no rectifier output. Review "Controls" section of this manual on Page 9, and correct any setting errors.
- **VI-SENTRY Controller Failure:** Check for the board status LED's. "Power ON" LED is illuminated continually when the board is powered and the on-board microprocessor is functioning. One of the Mode LED's will function if any one of the rectifier output modes is being controlled. Due to board complexity, replace defective controller with a known working controller.

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- Faulty Connections: Often broken or high resistance connections will lead to no rectifier output or intermittent output. Disconnect power, check and re-tighten all connections. Be especially aware of any oxidized, burnt or discoloured connections. Repair or replace as required.
- DC voltage at output lugs, but no current: The principle reason for this failure is a broken CP system cables beyond the rectifier. Investigate and repair broken cables.
- DC voltage at output lugs, current flowing to load, but no current reading on ammeter: This could be the result of a defective ammeter, faulty leads, or failure of a metering switch. Repair or replace defective components.

B. LIMITED RECTIFIER OUTPUT CURRENT: This fault may be caused by any one or more of the following conditions:

- Improper Mode settings on the **VI-SENTRY** controller resulting in insufficient current to the CP system. Re-check settings and limits for current & voltage.
- Load resistivity too high for rating of the rectifier. This will usually be indicated by a "Voltage Limit" condition; where the Red LED is illuminated. Check anodes and ground bed resistance. Modify if necessary, or replace rectifier with a higher rated unit.
- Low supply voltage: Check incoming AC voltage to rectifier while rectifier is under load. Consult electrical maintenance personnel for adjustment if line voltage is low.
- Failure of SCR-Diode module: could result in "half-wave" output, which will yield only half of the rated output. Replace defective module with replacement.
- Failure of the VI-SENTRY Controller board. Remove defective board & replace with known working control board.

NOTE:

The CURRENT MODE LED (Green) or the VOLTAGE MODE LED (Red) will only be illuminated if the current or voltage set points are maintained. If a set point cannot be maintained by the **VI-SENTRY** Controller due to a setting beyond the range of the rectifier or due to lack of AC input, or due to half-wave conduction from the Diode-SCR bridge;

NO LED WILL ILLUMINATE!!

C. RECTIFIER FUSE BLOWS: Fuse failure may be due to the following:

- Fuses may blow due to either excessive current. In an automatic rectifier, this type of failure is mainly due to failure in the SCR-Diode module. Replace failed module and fuse, and re-energize rectifier.
- Fuses may blow due to excessive operating temperature. Excessive temperature on the fuse is typically caused by either corrosion or weakening of the gripping tension on the fuse clips or fuse holder. Replace defective fuse components when this occurs.

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D. RECTIFIER AC BREAKER TRIPS: AC Breaker tripping may be resolved as follows:

- Visually inspect the rectifier AC input surge arrestor for damage (usually located adjacent to the AC input terminals). If the housing of the arrestor is cracked or blackened, the arrestor has failed and should be replaced. Always replace the arrestor with one of the same type. If an immediate replacement cannot be obtained, the rectifier can operate without this arrestor for a limited period, however, please remember that the rectifier then has no protection against surges. In certain circumstances, the arrestor may also fail without any external signs of damage. As such, to ensure that the AC arrestor is not the problem and with the AC power "OFF", disconnect the wires of the arrestor from the circuit breaker terminals. If the rectifier circuit breaker now remains in the "ON" position when energized, the arrestor has failed and should be replaced.
- If the breaker still trips to the "OFF" position, disconnect the wires between output (bottom) terminals of the rectifier circuit breaker (CB1) and the AC primary of the main transformer (T1). If the rectifier circuit breaker now remains in the "ON" position when energized, the problem is further downstream in the rectifier.
- Reconnect the wires in the step above. Remove the wires from the transformer secondary to the SCR-Diode module. Note: This may be accomplished by open-circuiting the rectifier secondary fuse; if so equipped. If the breaker still trips to the "OFF" position, the main transformer has most likely failed and should be replaced (consult the factory for a replacement).
- Another possibility is that the AC configuration terminals of the main transformer (T1) (for dual input types only) are incorrectly set for the actual AC input voltage applied to the rectifier. Please confirm that these terminals are configured properly (refer to the electrical schematic) for the AC voltage being applied.
- The final possibility is most likely that the rectifier AC input circuit breaker itself has failed and will require replacement.

E. RECTIFIER OUTPUT IS INTERMITTENT: Possible causes for erratic are:

- Broken or loose connections. Check all rectifier connections for loose or broken connections. Include the wiring connections to the **VI-SENTRY** Controller.
- Check if built-in or field attached interrupters are in operation.

TROUBLESHOOTING SUMMARY:

As rectifier problems in automatic units can be more easily solved by having a good working knowledge of the application and the workings of the rectifier, review this manual to ensure recommended installation practices have been followed. If a problem cannot be solved, please contact your rectifier dealer or the factory for technical assistance.



INTEGRATED RECTIFIER TECHNOLOGIES, INC.

15360 - 116 Avenue, Edmonton, Alberta, Canada T5M 3Z6

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RECTIFIER DATA SHEET

MODEL No. : CCASF5 60-34 MaQa SERIAL No. : 07R-0408 DATE : MAY 04, 2007
 CUSTOMER : LORESCO INC. M.S.O. No. : 002717-3-2 P.O. #: JT033007
 AC VOLTS : 115 / 230 INPUT V.A. : 3,800 DC VOLTS : 60 TYPE : AUTO-CURRENT
 AC AMPS. : 33.0 / 16.5 PH. : 1 CYCLES : 60 DC AMPS. : 34 CCTS. : SINGLE

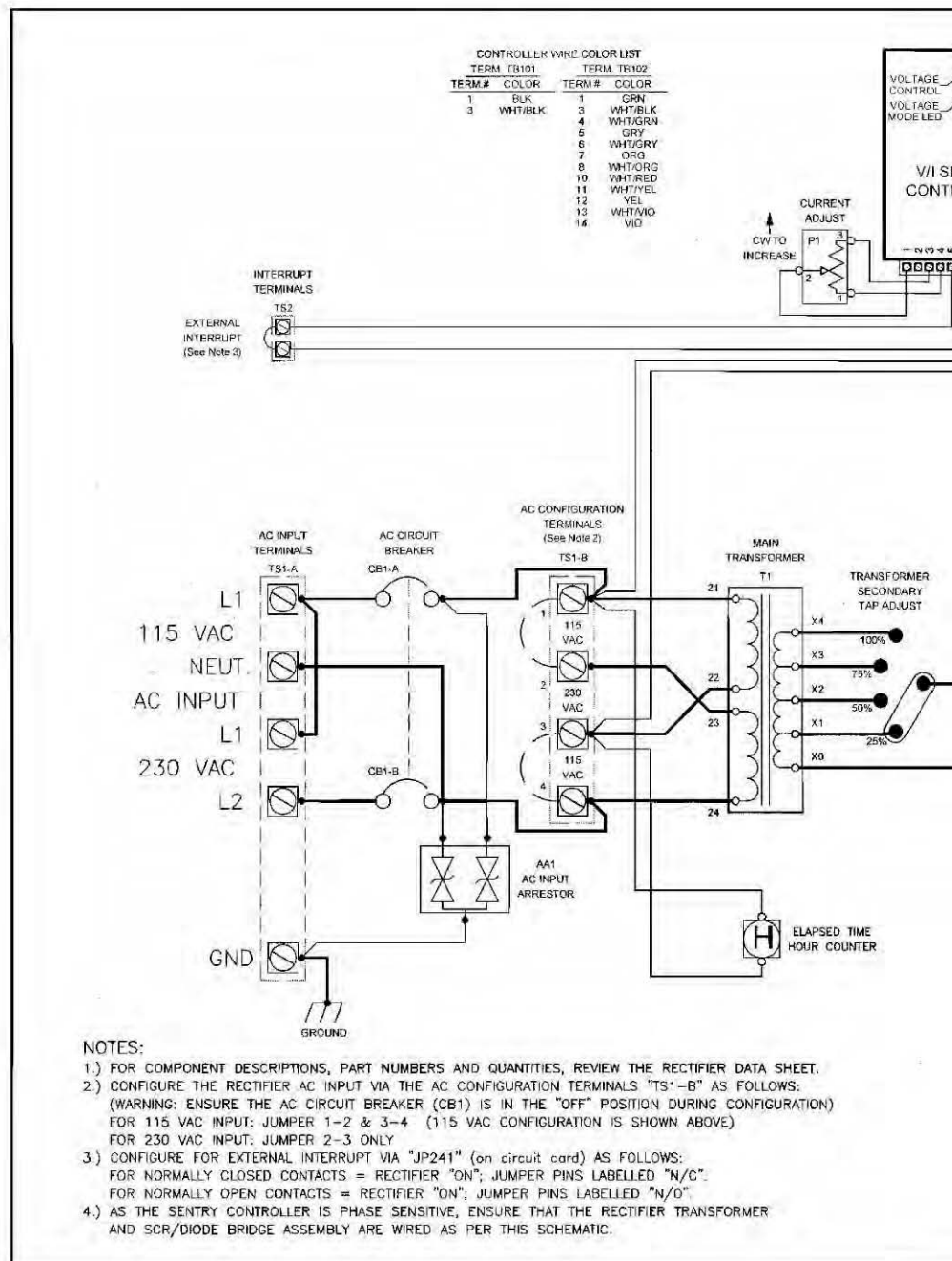
QTY.	ITEM NUMBER	COMPONENT	COMPONENT DESCRIPTION
1	090-A-0200	ENCLOSURE	A-2, 12 GAUGE MILL-GALV. STEEL, WHITE
1/1	092-A-0200/0205	FRAME (LEFT & RIGHT)	A-2, 12 GAUGE MILL-GALV. STEEL, WHITE
2	092-A-0210	TX. MOUNTING BRACKET	A-2, 12 GAUGE MILL-GALV. STEEL, WHITE
1	095-M-A200	INSTRUMENT PANEL	NEMA "XX", 1/4" x 13.25" x 16.25"
1	A-2 ADVANTAGE	AC INPUT CONN. STRIP, "TS1"	1/4" TERMINALS WITH BARRIER
1	031-B-035A/600V	AC CIRCUIT BREAKER, "CB1-A"	35.0 AMPERE, 600 VAC, 1-POLE
1	031-B-020A/600V	AC CIRCUIT BREAKER, "CB1-B"	20.0 AMPERE, 600 VAC, 1-POLE
1	008-A-1124	AC SURGE ARRESTOR, "AA1"	115/230 VAC, 1-PHASE, 3-WIRE
1	008-P-279-1	AC ARRESTOR BRACKET	16 GAUGE ALUMINUM, BARE
1	T-060034-F16S04A	MAIN TRANSFORMER, "T1"	115/230 VAC, 60 Hz, 1-PH, SCR-CONTROL, 4-SEC. TAPS
4	088-S-00300	TRANSFORMER STRAP	EI-300, ZINC DICHROMATE PLATED
1	078-C-01000	AC SECONDARY TAP BAR	COPPER, NICKEL PLATED, 1/8" x 0.75" x 2.5"
2	054-K-0014P	KNOB, TAP BAR ADJUST	PLASTIC, BLACK c/w BRASS INSERT 1/4-20 NC
2	037-R-0040	TX. SECONDARY FUSE, "F1"	40 AMPERE, 250 VOLT, TIME LAG
2	038-C-0020	AC SECONDARY FUSE CLIP	COPPER, NICKEL PLATED, 13/16" DIA. x 2.00"
1	002-TB-175/1200V	SCR / DIODE MODULE, "BR1"	70 AMPERE, 1200 V, c/w FREE-WHEELING DIODE
1	066-P-0486	HEATSINK, UNDRILLED	CLEAR CHROMATE
1	007-G-0S20K130	BRIDGE AC VARISTOR, "MOV1"	130 VAC (RMS), 74 JOULES, 22.5 mm, 2-WIRE
1	061-F-0100	VI-SENTRY CONTROLLER, REV 1.0	CURRENT-VOLTAGE CONTROLLER, 115 VAC
-		VI-SENTRY MICRO FIRMWARE	FIRMWARE VERSION 16C622AS-04.00
1	062-P-0300	CONNECTOR, "TB101"	3-PIN, 3.5mm SPACING
1	062-P-1400	CONNECTOR, "TB102"	14-PIN, 3.5mm SPACING
1	026-A-1010	POTENTIOMETER, "P1"	PANEL MOUNTED, SINGLE-TURN, 10K.
1	047-K-01000	POTENTIOMETER KNOB	0.78" DIA., BLACK
2	055-S-5000	INTERRUPT TERMINALS, "TS2"	5-WAY BINDING POST, BLACK
1	041-C-0010/042-C-0075	VOLTMETER / SCALE, "V"	3.5", 0 -75 VOLTS F.S.D. / 60 VOLT RED LINE
1	041-C-0010/042-C-0040	AMMETER / SCALE, "A"	3.5", 0-40 AMPERES F.S.D. /34 AMPERE RED LINE
1	043-B-SW50040	BLOCK SHUNT, "SHT"	40 AMPERE - 50mV, TYPE "SW"
1	008-D-1002	DC SURGE ARRESTOR, "DA1"	100 Vpeak, 2-TERMINAL
2	051-C-0030	DC OUTPUT LUG TERMINALS	#1/0-6 AWG, 1-HOLE, COPPER, NICKEL PLATED
1	041-T-06000	ELAPSED HOUR COUNTER	120VAC, 99,999.9 HR. LCD-DISPLAY, (2-1/2" ROUND)
1	VI-C0010	O&M MANUAL	8.5" x 11", INSIDE PROTECTIVE PACKET
1	CCF1-H1B121-MaQa(C)	ELECTRICAL SCHEMATIC	11" x 17", FOR INCLUSION WITH O&M MANUAL

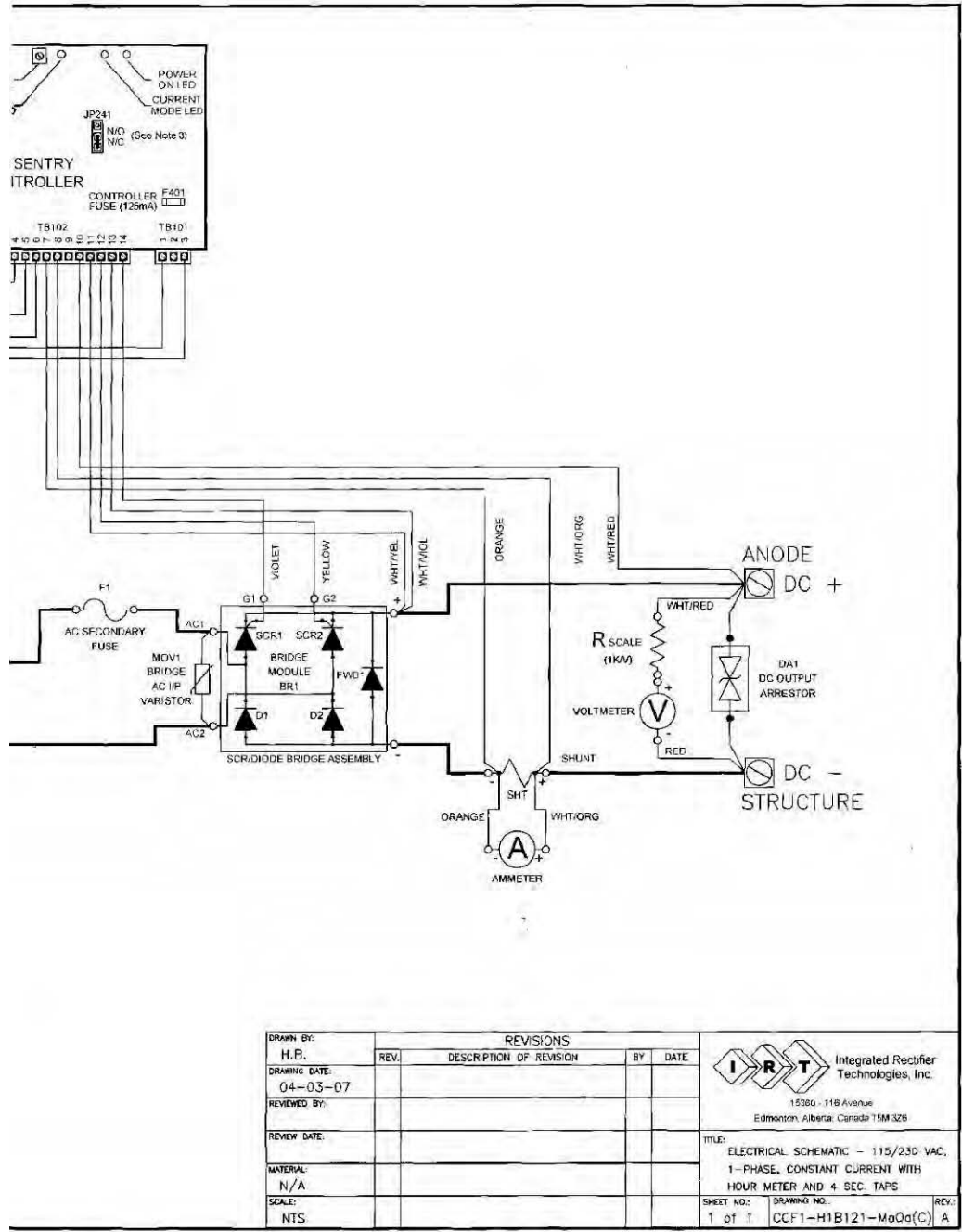
NOTES:

1. OPTION "Ma": Rectifier equipped with digital LCD type hour meter.
2. OPTION "Qa": Rectifier equipped with 4 Secondary tap setting to give 25%, 50%, 75% & 100% rated output.

AC PRIMARY: #10 TEW AC SECONDARY: #8 EXANE DC OUTPUT: #8 TEW

REV. 0





Elevated tank application

C.P. SENTINEL AUTOMATIC TYPE CATHODIC PROTECTION RECTIFIER

INSTALLATION, OPERATION, & MAINTENANCE MANUAL

REV. 3.0 NOVEMBER, 2004

SINGLE PHASE INPUT

MODEL:

CP – "ON" POTENTIAL CONTROL

CI – "IR FREE" POTENTIAL CONTROL



INTEGRATED RECTIFIER TECHNOLOGIES, INC.

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APPENDIX:

INCLUDES ELECTRICAL SCHEMATIC, RECTIFIER DATA SHEET, AND ANY
OTHER OPTIONAL INFORMATION

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INTRODUCTION

Corrosion of underground structures (pipelines, well casings, etc.) is a process that occurs every minute of every day. As such, continuous protection is required to effectively prevent damage that could cost a company significantly in lost revenues, manpower, and equipment. The proper selection, installation, and operation of a suitable corrosion prevention system can be crucial to ensure that this costly damage does not occur. For well-coated structures, structures with small surface areas, or where minimal Cathodic Protection is required, a "sacrificial" type corrosion prevention system may be used. For poorly coated structures, structures with large surface areas, or where a larger amount of Cathodic Protection is required, an "impressed current" type corrosion prevention system is required. One key component of an impressed current corrosion protection system is a Cathodic Protection rectifier. A rectifier is a device that is used to convert "alternating current" (AC), as provided by the power utility, to "direct current" (DC), as is required for Cathodic Protection. The rectifier should be selected based on the type of control required for the specific application, the amount of Cathodic Protection required to provide effective protection, and the reliability of operation in the subject environment. **IRT Integrated Rectifier Technologies, Inc.** manufactures Cathodic Protection rectifiers that exceed industry standards for superior corrosion prevention and, as such, an IRT rectifier unit is a smart investment for any company.

IRT Integrated Rectifier Technologies, Inc. Cathodic Protection rectifiers and associated products are designed by a knowledgeable engineering team with years of experience in the corrosion field and manufactured by skilled technicians with a dedication to quality. The IRT units are designed with superior components to provide a high quality, reliable rectifier with an economic cost for your application. IRT maintains a large volume of in-stock components and sub-assemblies to ensure that orders can be shipped to you in the shortest time frame possible.

IRT products are sold and serviced by leading corrosion prevention engineering companies throughout North America and Internationally. These companies have superior expertise in the corrosion industry and have the personnel to meet all of your corrosion prevention system requirements including design, installation, and maintenance. IRT products are also available through leading material supply companies throughout North America.

Rectifiers manufactured by **IRT Integrated Rectifier Technologies, Inc.** are guaranteed against defects in design, workmanship, or material for a period of one year from the time of shipment from our facility. Please refer to our warranty statement for further details.

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INTEGRATED RECTIFIER TECHNOLOGIES, INC.

DELIVERY INSPECTION

Although the rectifier unit may not be scheduled for immediate installation, we recommend that it be thoroughly inspected, both externally and internally, upon receipt to ensure that no damage has occurred during shipment. Please remember that although the outside of the rectifier packaging may not show any signs of damage, there may be internal damage that will not be apparent until the outer packaging is removed. Any damage, whether internal or external, must be reported to the freight carrier immediately. If any damage has occurred during shipment, an indication of this should be made on the freight paperwork, the shipment should then be accepted, and a claim filed with the freight carrier. Please ensure to retain the original packaging that may indicate how the damage occurred.

If damage has occurred during shipment and repairs or a return to the factory is required, please contact us, or your local IRT distributor, with the Serial Number and the Model Number of the rectifier. This information is crucial for us to determine the rectifier unit in question and to be able to provide suitable assistance. A Return Materials Authorization (RMA) number must be obtained from the factory prior to return of any damaged rectifier units.

PRE-INSTALLATION STORAGE

If the rectifier unit is to be stored prior to installation, it is recommended that it be stored in a dry area, preferably indoors. If the unit is to be stored outdoors for an extended period of time, it is recommended that it be placed on a raised surface (pallet or platform) and covered with a protective sheet or tarp to ensure the packaging does not deteriorate due to rain or snow. Whether stored indoors or outdoors, the unit should be placed in an area where it is protected from accidental damage from moving vehicles or equipment. Ensure that the rectifier unit is transferred to and from the storage facility using proper handling techniques.

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SAFETY PRACTICES

This symbol denotes a possible shock or electrical hazard.

**DO NOT INSTALL, REMOVE, or REWIRE
THIS EQUIPMENT WITH POWER APPLIED!!**



As Cathodic Protection rectifiers are connected to the AC utility power, electrical shock hazards are present within the rectifier units. It is recommended that only qualified electronic or electrical personnel operate and maintain these units and that those personnel familiarize themselves with the areas of possible hazard within the unit. Following these practices can enhance the safety of personnel.

- 1.) Prior to site maintenance or inspection, familiarize yourself with the rectifier and conditions at the site.
- 2.) Prior to doing any maintenance or troubleshooting on a rectifier unit, familiarize yourself with any possible hazard points within the unit by reviewing the electrical schematic and the physical layout of the rectifier.
- 3.) Whenever possible, set the AC disconnect from the power utility to the "OFF" position prior to starting any work on the rectifier unit. Even with the rectifier AC input circuit breaker in the "OFF" position, hazardous voltages are still present at any terminals connected to the rectifier AC input terminals. Always tag and lock out the disconnect to ensure others do not energize it while you are completing the rectifier work.
- 4.) Prior to opening the rectifier enclosure door, lightly touch the back of your hand to the enclosure latch. If you feel an electrical tingle, set the fused AC disconnect to the "OFF" position and contact an electrician for assistance.
- 5.) When taking readings across the rectifier terminals, it is recommended to use only one hand, if possible.

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GENERAL INSTALLATION RECOMMENDATIONS

To ensure reliable, long-term operation of the Cathodic Protection rectifier, proper installation of the unit is required. Though most installation sites differ, there are several key guidelines that should be followed.

- a) Prior to installation, check the connections (especially the electrical connections) on the rectifier unit to ensure that nothing has become loose during shipment. It is also recommended that if any scratches occur to the enclosure during installation, that these points be touched-up to prevent corrosion on the enclosure.
- b) Selecting the site of installation is a very important factor. The rectifier should be installed in a location that is easily accessible by company personnel for regular adjustment, monitoring, and maintenance. However, it should not be located in areas where unauthorized personnel have easy access to the unit and may damage or vandalize it (i.e. residential areas, playgrounds, farm yards, etc.). The convenient access to AC power and the cathodic protection DC connections must also be considered when choosing the rectifier location.
- c) Proper ventilation and cooling of the rectifier unit is essential and must be considered when choosing a suitable location. Air-cooled rectifiers are cooled by the natural convection of cool air drawn into the bottom of the rectifier enclosure, passing over the internal components, and the resultant warm air expelled from the top or sides of the enclosure. Oil-cooled rectifiers are cooled by the natural circulation of oil from the bottom to the top of the rectifier tank, over the internal components, and the resultant heat is radiated from the upper walls of the rectifier tank. As such, when choosing the installation site for the rectifier, adequate spacing should be allowed for around the sides of the rectifier unit. The rectifier should not be located near sources of heat such as exhaust vents, power generators, etc. If possible, place the rectifier unit in an area where it will be shaded during the hottest part of the day. If the rectifier is to be installed in an area with a high ambient temperature and minimal natural shading, a protective sunshade is recommended.
- d) The rectifier unit should be mounted on a secure surface. Ensure that the wall, pole, frame, or mounting pad is designed to hold the full weight of the rectifier unit.
- e) If the rectifier is to be installed in an area subject to frequent lightning activity, upgraded, high-energy type surge arrestors are recommended. If possible, do not locate the rectifier on a hill top where there increased chances of lightning strikes. Use of a low resistance ground rod(s) is recommended. Locate the ground rods adjacent to, but away from the rectifier, the ground bed, and incoming CP cables. Remember, most damaging voltage surges are the result of induced pickup rather than a direct strike.
- f) Do not install other equipment on or inside the rectifier enclosure without prior consent from the factory. Unauthorized equipment installation will invalidate the rectifier Warranty, as IRT has no control of the equipment added or the resultant detrimental affect to proper rectifier cooling / operation.

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RECTIFIER CONNECTIONS AT SITE

**DO NOT INSTALL, REMOVE, or REWIRE
THIS EQUIPMENT WITH POWER APPLIED!!**



After the rectifier has been installed in a suitable location, have a qualified electrician connect the rectifier unit to the AC supply following local and national codes. Please note that most electrical codes require a disconnect device between the AC power supply and the rectifier. Ensure that for dual AC input rectifiers (115 / 230 or 230 / 460 VAC), that the AC input terminal jumpers are properly configured for the actual AC input voltage being supplied and that the AC input wires are connected to the correct AC input terminals.

The grounding rod(s) should be connected to the ground lug terminal adjacent to the AC input terminals within the rectifier.

Next, connect the cable(s) from the anode bed to the RECTIFIER POSITIVE output lug terminal(s) and the structure cable(s) to the RECTIFIER NEGATIVE output lug terminal(s). Ensure that these cables are suitably sized for the expected current and the length of the cable run. Also, it is absolutely imperative that the polarity of DC connections is correct. A reversal of the DC cables can actually cause accelerated corrosion and eventually, severe damage to the structure to be protected.

C.P. SENTINEL Automatic Potential Controlled Rectifiers require two additional connections for proper operation, the Reference Electrode and the Structure Sensing leads. Connect the Reference Electrode to the rectifier terminal marked "REFERENCE" (REF) and the Structure Sensing lead to the terminal marked "STRUCTURE" (STR). The Structure Sensing lead must be a separate non-current carrying lead connected to the protected Structure, usually adjacent the Reference Electrode.

APPLICATION NOTES:

1. Superior Potential Mode control is achieved by minimizing noise on the lead wires used for the REFERENCE Electrode & STRUCTURE sensing. It is recommended that lead lengths in excess of 25 feet or leads in noisy electrical environments be shielded in a separate conduit, or consist of shielded, twisted-pair conductors installed using recommended shielding practices.
2. **C.P. SENTINEL** Automatic Potential controlled rectifiers are equipped with "Loss-of-Reference" shutdown feature. Upon degrading or failure of the Reference Electrode, internal cell resistivity increases, and the voltage "reference" decreases. The natural condition for an automatic potential rectifier is to increase to full output to counter the reduced voltage sensed. This feature is designed to prevent structure coating failure due to excessive polarization if this cell failure condition occurs. If this type of rectifier is to be used in Current or Voltage Modes without a Reference Electrode attached, it will be necessary to jumper the REFERENCE- STRUCTURE hook-up terminals of the rectifier. The rectifier REFERENCE SELECT switch must be set to sense an active and functional Reference Cell input, or no output will occur from the unit. A "Loss-of-Reference" shutdown will be evident by the analog Potential Meter reading full scale or if equipped with a digital Potential Meter reading overload; first digit a "1" followed by remaining digits blank.

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RECTIFIER OPERATION MODES

Depending upon the Model and the Options supplied with the rectifier, the **C.P. SENTINEL** Automatic Rectifiers are available with the following modes of operation:

CONSTANT VOLTAGE MODE: (SUPPLIED ON ALL MODELS)

In this mode the rectifier control circuitry automatically adjusts the rectifier output to maintain the VOLTAGE at the preset level. In this mode, the Current Set potentiometer determines the current limit. When operating in this mode, the RED LED is illuminated.

CONSTANT CURRENT MODE: (SUPPLIED ON ALL MODELS)

In this mode the Rectifier control circuitry automatically adjusts the rectifier output to maintain the CURRENT at the preset level. In this mode, the Voltage Set potentiometer determines the voltage limit. When operating in this mode, the GREEN LED is illuminated.

IR-FREE POTENTIAL MODE: (OPTIONAL)

In this mode the Rectifier control circuitry automatically adjusts the rectifier output to maintain the Reference Electrode to Structure POTENTIAL at the preset level. The Reference Electrode to Structure POTENTIAL is maintained free of the error caused by current flow in the anode-cathode circuit. IR-Free Potential mode is available on non-filtered single phase rectifiers only. In this mode, the CURRENT Set potentiometer determines the current limit and the VOLTAGE Set potentiometer determines the voltage limit. When operating in this mode, the YELLOW LED is illuminated.

NOTE:

C.P. SENTINEL Automatic Rectifiers encompass full galvanic isolation of the Reference Electrode and Structure input signals. Therefore it will be necessary to connect separate lead wires for the REFERENCE Electrode and STRUCTURE sensing.

"ON" POTENTIAL MODE: (OPTIONAL)

In this mode the Rectifier control circuitry automatically adjusts the rectifier output to maintain the Reference Cell to Structure POTENTIAL at the preset level. However, the Reference Electrode to Structure POTENTIAL is maintained while there is current flow in the anode-cathode circuit. In this mode, the Current Set potentiometer determines the current limit and the Voltage Set potentiometer determines the voltage limit. When operating in this mode, the YELLOW LED is illuminated.

MANUAL MODE: (OPTIONAL)

Rectifiers equipped with this option are supplied with a conventional manual tap-adjusted transformer in addition to the automatic control circuitry. This mode permits the operator to control the rectifier output by gating 'on' the Silicon Controlled Rectifiers to conduct as conventional diodes. Manual rectifier output control is achieved by switching the Automatic-Manual Switch to the Manual mode position and then adjusting the transformer secondary taps.

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THE SENTRY CONTROLLER

The C.P. *SENTINEL* Automatic Rectifiers are controlled by the IRT *SENTRY* Controller. Refer to the following layout of the *SENTRY* Controller for location of controls and jumpers:

NOTE:

This section will describe the Controls, Jumpers, Test Points and Adjustments of interest for field setup and operation, as performed by QUALIFIED TECHNICAL PERSONNEL. All Remaining Factory Settings & Calibrations **SHOULD NOT** be attempted or tampered with.

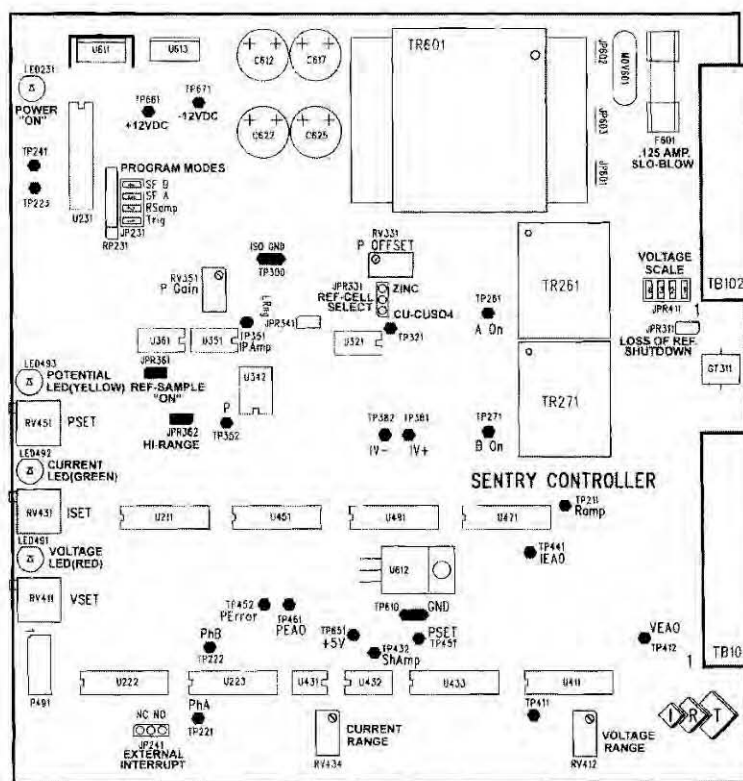


FIGURE 1.0 SENTRY CONTROLLER (FOR BOARD REV 2.0)

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CONTROLS:

Voltage, Current, and Potential settings are adjusted via three potentiometers available on the **SENTRY** Controller. These potentiometers are 20-Turn Trim-pots located at the end of the controller board opposite the wiring connectors. (Refer to Figure 1.0, Page 9).

VOLTAGE: Rectifier output voltage (or Voltage Limit) is set by potentiometer "**RV411**". Rectifier operation in Voltage Mode or Voltage Limit will be indicated by the Red LED "**LED491**", adjacent the Voltage Set Potentiometer.

CURRENT: Rectifier output current (or Current Limit) is set by potentiometer "**RV431**". Rectifier operation in Current Mode or Current Limit will be indicated by the Green LED "**LED492**", adjacent the Current Set Potentiometer.

POTENTIAL: On rectifiers equipped with this option: Rectifier Structure to Reference Electrode Potential is set by potentiometer "**RV451**", in conjunction with the "Press-to-Set/Actual" selector switch. Rectifier operation in the Potential Mode will be indicated by the Yellow LED "**LED493**", adjacent the Potential Set Potentiometer. Both Potential Set Point and Actual Structure-Reference Electrode potential may be read on the rectifier's potential meter via the "Press-to-Set/Actual" selector switch.

NOTE:

Depending upon the model and/or configuration of the rectifier ordered, one or more of these potentiometers may be mounted external of the controller board on the rectifier instrument panel. Consult your Rectifier Specification Sheet.

CAUTION!!

Do NOT attempt to alter the settings of any other trim pots on the controller board. These are factory calibrations and tampering with these settings could jeopardize proper operation and scaling of the **SENTRY** Controller.

JUMPER SETTINGS:

The **SENTRY** Controller is designed to adapt and accommodate a wide variety of field installations and control situations. To make this accommodation easier, please review the following Jumper functions and settings:

A. INPUT VOLTAGE SELECTION (JP601, JP602, & JP603)

INPUT VOLTAGE	JP601	JP602	JP603	COMMENT
115 VAC	INSTALLED	INSTALLED	OMITTED	DEFAULT POSITION
230VAC	OMITTED	OMITTED	INSTALLED	OPTIONAL POSITION

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B. PROGRAM MODES (JP231) USE WITH FIRMWARE VERSION 16G622AS-1.00

"JP231" SETTING	FUNCTION	COMMENT
JP231 – 1 (TRIG)	NOT SUPPORTED	NOT USED
JP231 – 2 (Rsamp)	INSTALLED: Reference Electrode Sampled just prior to SCR Gate-on	DEFAULT: Use in IR-Free mode & Choke Filtering
JP231 – 2 (Rsamp)	REMOVED: Reference Electrode Sampled after Zero-Crossing AC waveform	Use with AC Interference
JP231 – 3 (SF A)	Doubles SCR Gating "ON" & "OFF" times	INSTALLED (DEFAULT)
JP231 – 4 (SF B)	Doubles the "SF-A" SCR Gating "OFF" time	INSTALLED (DEFAULT)

C: EXTERNAL INTERRUPT (JP241)

"JP241" SETTING	FUNCTION
JP241 PINS 1 - 2	Normally Closed contacts = Rectifier output current (Optional Setting)
JP241 PINS 2 - 3	Normally Open contacts = Rectifier output current (Default Setting)

D: POTENTIAL MODE SETTINGS

JUMPER	FUNCTION – DESCRIPTION	COMMENT
JPR311, PINS 1-2	"Loss of Reference Shutdown" Enabled	INSTALLED
JPR331, PINS 1-2	Select Type of Reference Cell = CU-CUSO ₄ or Ag-CL	DEFAULT
JPR331, PINS 2-3	Select Type of Reference Cell = ZINC	OPTIONAL
JPR341, (CLOSED) JPR362, (OPEN)	Select Low Range (Max. Potentials less than ± 3.0 Volts)	OPTIONAL
JPR341, (OPEN) JPR362, (CLOSED)	Select High Range (Maximum Potentials > than ± 3.0 Volts)	DEFAULT
JPR361, PINS 1-2	Select Continuous "ON-Potential" Control & Sampling	DEFAULT

E: VOLTAGE RANGE SETTINGS: "JPR411"

Header "JPR411" is factory set to determine the available output range of voltage control.

OTHER CONTROLLER PARTS & FUNCTIONS

FUSE: "F601" is located on the circuit board near the board-mounted control transformer. This is a 0.125 ampere, slow-blow type of 5mm x 20mm metric style fuse. Replace with same fuse type and rating.

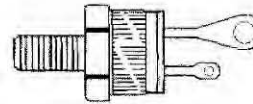
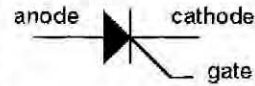
POWER ON LED: Controller "POWER ON" operation is indicated by "LED231", Yellow.

WIRING CONNECTORS: "TB101" & "TB102". These are 14-pin plug on connectors. Ensure all wiring connections are secure by tightening the screw terminals on these connectors.

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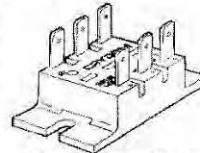
THE SILICON CONTROLLED RECTIFIER (SCR)

Automatically controlled rectifiers utilize phase control of the supplied 50 or 60 Hertz AC voltage using a solid-state device called a Silicon Controlled Rectifier (SCR). This device is similar to a conventional diode, but is equipped with an extra terminal for control called the GATE. Although akin to a diode, this device has unique properties of being able to block conduction of current when the device is forward biased until an appropriate signal is applied to the Gate terminal. Once the appropriate gate signal is applied, the SCR remains in conduction while forward biased, or until the current trough the device goes to almost zero.



The control of the rectifier DC output is accomplished by "gating on" the SCR at the point in the AC waveform necessary to produce the desired output. This output can be the regulated DC Voltage, the DC Current, the Structure to Reference Electrode Potential or a combination of the three modes of control. A minimum of two SCR's are required to achieve full control over the AC waveform. The two SCR's are configured with two diodes into a full-wave bridge configuration.

Often SCR's and diodes are combined into full-wave controlled rectification modules. Typically the modules used are comprised of two SCR's and two diodes with the cathodes of the 2 SCR's connected to the module Positive (+) terminal. SCR-Diode modules are then mounted to a suitably sized heatsink for cooling.



SCR-DIODE MODULE

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POTENTIAL CONTROL AND EXTERNAL IR DROP

NOTE:

This section applies only to *C.P. SENTINEL* Automatic Rectifiers which have been ordered and manufactured to function as IR-Drop Free Reference Electrode controlled outputs. Consult your Rectifier Specification Sheet.

In applying and operating IR-Drop Free *C.P. SENTINEL* Automatic Rectifiers, it is important that Cathodic Protection personnel are familiar with the methods & principles of using this type of rectifier to mitigate corrosion. Briefly described as follows:

Current flowing in the measurement circuit will cause a voltage drop (referred to the Ohm's Law equivalent of Current "I" multiplied by Resistance "R" or "IR"), which becomes incorporated into measurements as an error. In addition, any external currents flowing through the electrolyte in the area between the reference electrode and the structure will cause their own voltage drop, which also becomes part of the measurement as an additional error. Cathodic protection systems and AC & DC electrical power systems are some of the possible sources of these currents. The magnitude of errors from external IR drops can be substantial. To accurately maintain the required polarization potential on a given structure, these errors must be minimized during the design phase and then eliminated by electronic circuitry within the *SENTRY* Controller, which is used in the *C.P. SENTINEL* Automatic Rectifiers.

The *SENTRY* Controller removes the IR drop error from the potential measurement by interrupting the cathodic protection current supplied by the rectifier momentarily. This action produces an instantaneous voltage drop, which is considered to be the external IR Drop. The potential from Reference Electrode to Structure is measured immediately after this instantaneous drop, and is considered to be the "IR Drop Free" potential of the structure.

Clearly, this method only works with an impressed current cathodic protection system where all the rectifiers on that system can be interrupted simultaneously, and there are no other sources of current flowing through the electrolyte.

An issue that should be considered when using current interruption for instant-off measurements is: What is meant by instantaneous? The answer is not simple since it depends upon the structure, the electrolyte and the method of interrupting the current. Putting the answer in electrical terms, it depends upon the capacitance and the inductance of the circuit. IR drop free measurements can be made microseconds after current interruption on small, uncoated specimens in a low resistance electrolyte. Large coated structures, such as pipelines, or high resistance electrolytes, such as concrete, usually require several hundred milliseconds or more for IR-drop free measurements. Interrupting current on the AC side rather than on the DC side of the rectifier will increase the time delay because the circuit inductance is higher. An oscilloscope should be used if measurement precision is necessary; it should be either battery powered or connected through an isolation transformer to eliminate ground loops.

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GENERAL COMPONENT DESCRIPTION

When operating any equipment, it is a good practice to become familiar with the key components and the general operation of that piece of equipment. The following is a summary of the key components of a rectifier and their function.

The **AC Input Surge Arrestor** is a device that protects the rectifier components from voltage surges that may occur across the AC input of the rectifier. It does this by providing a bypass circuit for the resultant current from these high voltage surges after a specific voltage threshold has been reached. Most surge arrestors are designed to handle a certain number or energy value of surges prior to failing.

The rectifier **AC Input Circuit Breaker** (CB1) is a fully magnetic type that serves three key functions. It is used as an "OFF-ON" switch for the rectifier, it provides "short circuit" protection, and, to a lesser degree, provides input overload protection.

The rectifier **Main Transformer** (T1) provides full electrical isolation between the utility AC power and the Cathodic Protection DC circuit. It also steps the voltage up or down as required for the DC circuit and, for tap type units, provides a means of output adjustment.

The rectifier **AC Secondary Fuse** is a time lag or slow-blow type that provides protection from not only short-circuits or overloads in the DC output circuit but also in the diode bridge circuit.

The rectifier **SCR-Diode Bridge Assembly** is comprised of silicon controlled diodes (SCR's) and diodes configured into a full-wave bridge configuration. The SCR-diodes are supplied with suitably sized heatsinks to ensure that the SCR-diodes do not exceed 100°C at full rated output. The SCR-diode bridge controls and rectifies the AC secondary voltage of the transformer into DC voltage that can be used for Cathodic Protection. This DC voltage level is then automatically maintained by the **SENTRY** Controller in Potential, Current or Voltage Mode, as set by the operator.

A **Varistor** is supplied across the AC input to the diode bridge to provide additional protection from any voltage surges that may pass the main AC surge arrestor or be developed by the main transformer. A second varistor may also be supplied across the DC output of the diode bridge at special request.

The **Current Monitoring Shunt** is a block style calibrated resistor with an accuracy of 0.25%. The DC current and voltage rating are stamped into the body of the shunt. Shunts used in rectifiers equipped with digital meters will be either 1 Millivolt or 10 Millivolts per ampere, depending upon the rectifier output current rating.

The rectifier **Ammeter & Voltmeter** utilize an analog, taut-band type movement that provides $\pm 2\%$ accuracy. The DC output amperage of the rectifier is monitored by a meter connection across the calibrated test screws of the above shunt. The DC output voltage of the rectifier is monitored by a meter connection across the DC output terminals of the rectifier.

On Potential Controlled rectifiers, an additional **Potential Meter** is supplied to monitor the Structure to Reference Cell Potential, and the desired "Set Potential". This meter receives the potential reading from the **SENTRY** Controller.

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Potential Adjust Potentiometer is a front, panel-mounted multi-turn potentiometer used to set the required Structure to Reference Electrode potential required by the CP System. The setting can be read on the **Potential Meter** by activating the **Potential Switch** to the "Set" position.

The "**Set-Actual**" **Switch** permits the operator to monitor, via the rectifier Potential Meter, either the "**Actual**" potential or the "**Set**" potential of the rectifier. The "**Actual**" potential may be either free of IR-Drop error, as determined by the **SENTRY** Controller, or the "ON" potential, if the rectifier is equipped with filtering or if configured to operate in the "ON" potential Mode.

Metering Test Points (Optionally supplied) are located on the touch-safe instrument panel for purposes of verifying the digital meter readings. Metering Test Points are 0.093 diameter test jacks, with polarity and function as indicated by the silk screening on the panel. The "Potential" test points will indicate the potential voltage reading as determined by the "**POTENTIAL ACTUAL/SETPOINT**" toggle switch.

The **Reference Electrode (Cell) – Structure Input Terminal Block** is used to make field connections to the CP system Reference Cell and Structure sensing leads.

NOTE:

If no reference electrode is used, a jumper should be placed across these input terminals.

External Interrupt Terminal Block: (NOT Supplied on IR-Free rectifiers) Two terminals are provided on the front panel of the rectifier for purposes of interrupting the rectifier output using the **SENTRY** Controller. Jumper "**JP241**" on the controller board as required for Normally Open equals rectifier "ON" or Normally Closed contacts equals "rectifier "ON" as dictated by the interrupter being used. This is the preferred method to interrupt the rectifier by an external means. Special circuitry in the **SENTRY** Controller retains all of the operating parameters for resumption of control parameters after conclusion of an interrupt procedure and will not reset the slow start circuitry.

APPLICATION ALERT!!

IR-Free Automatic Potential controlled rectifiers typically do not utilize external interrupters when operating. For proper IR-Free potential control, the **SENTRY** Controller must not be impeded by external interrupter cycles as it controls the desired "Set Potential" of the CP system.

The **DC Output Surge Arrestor** is a device that protects the rectifier components from voltage surges that may occur across the DC output of the rectifier. It's operation and characteristics are similar to the AC input surge arrestor.

As many optional features / components are available for our customers, it is not practical for this manual to describe all of the possible options in detail. As such, it is recommended that the rectifier data sheet and the electrical schematic be reviewed in detail to become familiar with any features not detailed in this manual.

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INITIAL ENERGIZATION

After the rectifier has been properly connected to the AC supply and the DC output cables, (and Reference Electrode – Structure Sensing leads in the case of a potentially controlled type of rectifier) it is ready to be energized. Before energizing, always double-check both the AC and DC connections to ensure they are properly connected. Ensure that for dual input rectifiers (115 / 230 or 230 / 460 VAC), the AC input terminal jumpers are properly configured for the actual AC input voltage being supplied and that the AC input wires are connected to the proper terminals. For Current Controlled rectifiers, ensure that the rectifier is at its lowest control setting, by adjusting the "Current Adjust" potentiometer to zero. Use a multi-meter to verify static Reference Electrode – Structure potentials and record for later reference.



ENERGIZATION ALERT!!

If the rectifier is to be used on a CP system protecting the inside of a vessel ensure the vessel contains fluid sufficient to cover the anode system and the Reference Electrode.

Place the AC fused disconnect switch to the "ON" position and measure across the rectifier AC input terminals to ensure the voltage present is as expected. Next, place the rectifier AC input circuit breaker also to the "ON" position. The "POWER ON" Yellow LED on the **SENTRY** Controller will illuminate. The **SENTRY** Controller is designed with a "slow start" circuitry to minimize in-rush currents and to prevent the rectifier from starting at full output. This slow start time period will last from 3 – 10 seconds. There will be some deflection on the panel meters, especially the Potential Meter (although this deflection may be quite minimal on the Ammeter and Voltmeter). For units with a metering switch, ensure to set this switch to the "ON" position.

For **Automatic Current** rectifiers, simply adjust the "Current Adjust" potentiometer to the required current. This current will be read on the rectifier Ammeter. The rectifier ammeter can be verified by measuring the voltage (in Millivolts) across the calibrated test screws of the rectifier shunt (not across the connection bolts). To determine the current through the shunt from the millivolt reading taken, the following formula can be used:

$$\text{DC Current (I)} = \frac{\text{Measured Shunt Voltage (Millivolts)} \times \text{Rated Shunt Current}}{\text{Rated Shunt Voltage (50 Millivolts typical)}}$$

Note: Rated shunt current and voltage values are stamped onto the body of the shunt and are also shown on the rectifier data page.

The ammeter can also be verified with an external DC clamp-on type meter, if available.

It is recommended that all initial energization readings be recorded for future reference. Useful readings to record are structure potential levels prior to energization, AC input voltage & current, DC output voltage and current, tap or adjustment dial setting, structure potential levels after energization, as well as any observed problems or possible future concerns with the installation, in general.

For Automatic Potential Rectifiers, activate the Potential Switch to the "SET" position and observe the "SET" level of potential control on the Potential Meter. Adjust the required potential control level with the Potential Adjust potentiometer to the desired level of control. Release the Potential Switch and observe the "Actual" potential on the Potential Meter. When operating in this mode, the Yellow LED will be illuminated. It is important to note that if the

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potential control "Set" level cannot be initially attained due to the polarization time of the Structure, the rectifier will ramp up the DC output to either the Voltage set point (Voltage Limit; Red LED illuminated) or the Current set point (Current Limit; Green LED illuminated). Once the potential control "Set" level is attained, the **SENTRY** Controller will automatically revert into Potential Mode and maintain the Structure to Reference Electrode potential at the preset level. The Yellow LED will then be illuminated.

A NOTE ABOUT POTENTIAL READINGS!!

The **SENTRY** Controller is designed to provide IR-Free potential readings for control and for display to the Potential Meter. This reading will differ from the measured Structure-Reference Electrode inputs into the rectifier by the IR-Drop error. (Refer to description on Page 13) The "Actual" potential from the **SENTRY** Controller will only correspond to the measured Structure-Reference Electrode inputs into the rectifier with no current flowing; i.e., at no load. On rectifiers equipped with efficiency filters, true IR-Free operation cannot be attained. The "Actual" potential will equate to the Structure-Reference Electrode potential with minimal IR-Free error.

APPLICATION NOTES:

1. Remember, the **C.P. SENTINEL AQUA-LINE** rectifiers are equipped with "Loss-of-Reference" shutdown feature. The rectifier "REFERENCE SELECT" switch must be set to sense an active and functional Reference Cell input or no output will occur from the unit. Alternately, jumper the "REF. CELL" inputs on the front of the rectifier panel to obtain a current output. A "Loss-of-Reference" shutdown will be evident by the digital Potential Meter reading overload; first digit a "1" followed by remaining digits blank.
2. To function in current mode up to rated current, the output of the rectifier cannot be limited by either the "VOLTAGE SET" or the "POTENTIAL SET" potentiometers.

Rectifiers equipped with MANUAL MODE Option: Adjustment of rectifiers equipped with this option requires the "Automatic-Manual" selector switch be switched to the "Manual" position. Start the rectifier with the Coarse & Fine taps set to their lowest level (Coarse "A" - Fine "1"). Observe and record if necessary the rectifier output currents and voltage levels, and the polarization level of the Structure being protected. Incrementally, increase the transformer tap settings until either target current or polarization levels are attained. The **SENTRY** Controller is NOT required for manual mode, and may be removed for repair if it is not functioning correctly.

After the structure potential readings have been taken and prior to leaving the site, it is recommended that the DC output connections to the rectifier be rechecked to ensure a secure connection. It is also beneficial to recheck the rectifier to ensure that all air inlet and outlet venting on the enclosure is not obstructed in any manner. The rectifier O&M manual should be securely set in its holder (for small rectifiers without a manual holder, it is recommended that the manual be kept with the main operator or in the control room of the closest station). Also verify that all holes within the enclosure (other than the venting screens) are suitably plugged (such as unused conduit knockouts). For rectifier units with "OFF-ON" meter switches, ensure that the switch is in the "OFF" position prior to leaving the site.

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REGULAR MAINTENANCE & ADJUSTMENT

The basis for any effective CP system is routine documentation & maintenance. Despite the rectifier maintaining the DC output "automatically", it is recommended that the rectifier be checked and adjusted if necessary at least twice per year. Some local regulatory bodies require a monthly or semi-monthly check to ensure proper protection levels are being maintained. These checks also allow you to ensure that the rectifier has not been damaged. When completing this maintenance and adjustment check, it is recommended that all readings and observations be recorded in the site file. With regular maintenance checks and by maintaining good records, future troubleshooting and repair costs can be reduced.

Prior to arriving at the site for the rectifier maintenance check, it is recommended that the technician review the existing rectifier site file to gain familiarization with the subject rectifier and site conditions. Upon arriving at the rectifier site, a visual check should be completed to determine if any changes have occurred. Things to look for are signs of new underground construction, buildings, pipeline tie-ins, bonds, etc. Prior to adjustment of the rectifier, it is recommended that structure potential readings be taken, to determine the adjustment level required. Even if the potential levels are within the required range, the rectifier should still be checked for proper operation.

When approaching the rectifier, ensure that no items have been placed near the rectifier enclosure in such a manner as to block the venting, either on the bottom or sides. As the vent openings on the rectifier enclosure are screened, there should be no refuse inside from birds or larger insects. However, after opening the door of the enclosure, ensure that there has been no significant accumulation of dirt, snow, or other small debris at the bottom of the enclosure, which may adversely affect proper venting.

DO NOT INSTALL, REMOVE, or REWIRE THIS EQUIPMENT WITH POWER APPLIED!!



Prior to any adjustment of the rectifier, measure and record the "As Found" readings of the rectifier (DC voltage, DC amperage, etc.). Next, set the rectifier circuit breaker and the utility disconnect to the "OFF" position to allow for a detailed rectifier inspection.

At least once a year the rectifier should be inspected for loose electrical connections that could eventually cause damage to the electrical panel, wiring, or rectifier components. If an electrical connection becomes loose, the resistance of the connection increases and causes it to heat up. This additional heat will cause the connection to oxidize and become even higher resistant until a failure occurs. The best way to check for a heated connection is with a temperature probe, however, as these are not typically standard issue for Cathodic field maintenance, the visual inspection method will suffice. First, visually inspect all of the main electrical connections within the rectifier for signs of discoloration on the connection terminal, the electrical panel, or the wire attached to the terminal. Key points to check are the DC output lug terminal connections and the fuse holder connections. If you see a suspect connection, use a wrench or other suitable tools to see if the connection is indeed loose. (Note: Be careful when touching these types of connections with your hand as the temperature of loose high current connections can cause a significant burn.) If you do find a loose connection, it should be secured with suitable tools (make sure to secure both the front and rear of the double-nutted panel connections). If a loose connection has already caused damage to the electrical panel, the panel should be repaired or replaced, as re-tightening a connection on a degraded panel will most likely still lead to a future failure.

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Certain main components within the rectifier should also be inspected for signs of over-heating or other damage.

The main isolation transformer (T1) within the rectifier is designed to operate at a fairly high temperature and thus is usually somewhat discoloured. However, it should not be extremely dark or black. If it is, this could indicate insufficient / blocked venting or a problem within the transformer itself.

The AC primary, AC secondary, and the DC output surge arrestors should be checked to ensure that a significant voltage surge has not damaged them. Signs of damage to an arrestor device are usually visually noticeable by a blackened or cracked housing. Please note however that sometimes the operational status of an arrestor is not discernable visually and requires further checking (see Troubleshooting section).

The rectifier fusing should also be checked for overheating. If the fusing is a bolt-on type (for larger rectifier units), ensure that the fastening studs or bolts are secure on both the front and rear. Many smaller rectifier units utilize the "clip-type" fuse connectors that are very convenient for fuse replacement but are also infamous for becoming loose and oxidizing over time. However, with regular checks and maintenance, problems can be avoided. For this type of connection, if oxidation is apparent, the fuse should be removed and both the fuse and the fuse contact surface of the clips cleaned up with some very fine sand paper or emery cloth (only the oxidation layer should be removed, not the protective coating on the copper). If the fuse clips have lost tension, they should be replaced. If replacements are not immediately available, the clips can be "squeezed" together and should then provide a suitable short-term connection to the fuse. A notation should be made however, in the site inspection form for replacement on the next maintenance check. The connection hardware on each fuse clip should also be checked and re-tightened if necessary.

If, after completing the inspection on the rectifier unit, a problem is found other than just a loose connection, refer to the "Troubleshooting" section of this manual. If no problems have been found, the rectifier can be adjusted to a new DC output setting (if deemed required based on the "as-found" structure potential levels). As per the adjustment procedure indicated in the "Initial Energization" section, adjust the DC output of the rectifier to the level required to provide suitable protection to the structure. If the rectifier is adjusted to or near its maximum rated output, future replacement of the rectifier with a larger unit or the addition of anodes may need to be considered. If the required "target" DC output current from the rectifier varies significantly over the year due to load resistance changes, maintenance checks should be done frequently.

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TROUBLESHOOTING

If a problem is found with the rectifier during the maintenance inspection or reported by the local operator, the following troubleshooting procedure can be followed to determine the cause.

The only way to effectively determine the cause of a failure in any piece of equipment is to conduct a systematic analysis of the function and operation of the key components. For this troubleshooting procedure, we shall review the possible faults that may occur starting from the DC output and working back to the AC input.

CAUTION!!

Please be advised that hazardous voltages are present within the rectifier unit even with the rectifier AC input circuit breaker in the "OFF" position. Extreme care should be observed when taking measurements on the front of the instrument panel or the side AC input panel. Only qualified electronic or electrical technicians should attempt internal troubleshooting of the rectifier. The fused AC disconnect should be set to the "OFF" position prior to any internal rectifier maintenance or repair.

Please refer to the Rectifier Specifications Sheet, Electrical Schematic supplied with each rectifier and to the **SENTRY** Controller layout on Page 9 of this manual for component descriptions and test points. Common rectifier failures can be summarized and corrected as follows:

A. NO RECTIFIER OUTPUT CURRENT: This fault may be caused by any one or more of the following conditions:

- **No AC Present:** Check incoming utility supply for the presence of voltage and that it is correct for the rating of the rectifier. Consult your electrician or electrical utility to correct this problem.
- **Rectifier AC Breaker Tripped:** First: Do a visual inspection as described in the Maintenance & Adjustment section of this manual. Secondly, attempt to reset the breaker and observe rectifier output. If the rectifier fails to function correctly, continue with this troubleshooting procedure.
- **Blown Fuse:** Check all rectifier fuses, including the control fuse located on the **SENTRY** Controller circuit board. Replace as required with the identical type, size and rating as supplied. One spare for each fuse used in the unit is supplied with each rectifier.
- **Check Interrupt Circuit:** It is possible for field attached external interrupter to hold the output "Off". Refer to Page 11, Section "C" and Page 15 "External Interrupt Terminal Block" and correct any possible interrupter setting errors.
- **Improper Settings:** Review the settings on the **SENTRY** Controller for Voltage, Current and Potential (if applicable). Any one of these potentiometers set to "zero" will result in no rectifier output. Review "Controls" section of this manual on Page 10, and correct any setting errors.
- **SENTRY Controller Failure:** Check for the board status LED's. "Power ON" LED is illuminated continually when the board is powered and the on-board microprocessor is functioning. One of the Mode LED's will function if any one of the rectifier output modes is being controlled. Due to board complexity, replace defective controller with a known working controller.

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- Faulty Connections: Often broken or high resistance connections will lead to no rectifier output or intermittent output. Disconnect power, check and re-tighten all connections. Be especially aware of any oxidized, burnt or discoloured connections. Repair or replace as required.
- DC voltage at output lugs, but no current: The principle reason for this failure is a broken CP system cables beyond the rectifier. Investigate and repair broken cables.
- DC voltage at output lugs, current flowing to load, but no current reading on ammeter: This could be the result of a defective ammeter, faulty leads, or failure of a metering switch. Repair or replace defective components.
- Failure of Reference Electrode: The **SENTRY** Controller is equipped with "Loss of Reference Electrode" shut-down circuitry to prevent coating damage due to excessive polarization upon failure Reference Electrode. Replace defective Reference Electrode and re-energize rectifier. Refer to Page 7.

B. LIMITED RECTIFIER OUTPUT CURRENT: This fault may be caused by any one or more of the following conditions:

- Improper Mode settings on the **SENTRY** controller resulting in insufficient current to the CP system. Re-check settings and limits for current, voltage and potential (If applicable).
- Load resistivity too high for rating of the rectifier. This will usually be indicated by a "Voltage Limit" condition, where the Red LED is illuminated. Check anodes and ground bed resistance. Modify if necessary, or replace rectifier with a higher rated unit.
- Low supply voltage: Check incoming AC voltage to rectifier while rectifier is under load. Consult electrical maintenance personnel for adjustment if line voltage is low.
- Excessive AC interference on Reference Electrode to Structure inputs may reduce the rectifier DC output (on Potential controlled rectifiers). Although equipped with circuitry to minimize AC interference on the potential measuring circuit, excessive amounts of interference can cause the **SENTRY** Controller to reduce output current or voltage in response to this outside interference. Review installation practices outlined on Page 7.
- Failure of SCR-Diode module: could result in "half-wave" output, which will yield only half of the rated output. Replace defective module with replacement.
- Failure of the **SENTRY** Controller board: Remove defective board & replace with known working control board.

C. POTENTIAL SET POINT NOT MAINTAINED: This fault may be due to one or more of the following conditions:

- Rectifier output being limited by either the Voltage Limit or the Current Limit. Adjust these limits to the maximum rating of the rectifier.
- Rectifier output being limited by the Manual Tap adjustment (On rectifiers equipped with this option) Sufficient voltage must be supplied from the transformer taps to maintain the set point potential.
- Failure of the Reference Electrode results in limited or no output. See Page 7.
- Excessive AC input on Reference Cell – Structure leads. See Item "B", above.
- Defective "Press-to-Set" selector switch. Oxidized contacts could result in the "Set Potential" not being switched correctly into the **SENTRY** Controller.

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D. RECTIFIER FUSE BLOWS: Fuse failure may be due to the following:

- Fuses may blow due to either excessive current. In an automatic rectifier, this type of failure is mainly due to failure in the SCR-Diode module. Replace failed module and fuse, and re-energize rectifier.
- Fuses may blow due to excessive operating temperature. Excessive temperature on the fuse is typically caused by either corrosion or weakening of the gripping tension on the fuse clips or fuse holder. Replace defective fuse components when this occurs.

E. RECTIFIER AC BREAKER TRIPS: AC Breaker tripping may be resolved as follows:

- Visually inspect the rectifier AC input surge arrestor for damage (usually located adjacent to the AC input terminals). If the housing of the arrestor is cracked or blackened, the arrestor has failed and should be replaced. Always replace the arrestor with one of the same type. If an immediate replacement cannot be obtained, the rectifier can operate without this arrestor for a limited period, however, please remember that the rectifier then has no protection against surges. In certain circumstances, the arrestor may also fail without any external signs of damage. As such, to ensure that the AC arrestor is not the problem and with the AC power "OFF", disconnect the wires of the arrestor from the circuit breaker terminals. If the rectifier circuit breaker now remains in the "ON" position when energized, the arrestor has failed and should be replaced.
- If the breaker still trips to the "OFF" position, disconnect the wires between output (bottom) terminals of the rectifier circuit breaker (CB1) and the AC primary of the main transformer (T1). If the rectifier circuit breaker now remains in the "ON" position when energized, the problem is further downstream in the rectifier.
- Reconnect the wires in the step above. Remove the wires from the transformer secondary to the SCR-Diode module. Note: This may be accomplished by open-circuiting the rectifier secondary fuse, if so equipped. If the breaker still trips to the "OFF" position, the main transformer has most likely failed and should be replaced (consult the factory for a replacement).
- Another possibility is that the AC configuration terminals of the main transformer (T1) (for dual input types only) are incorrectly set for the actual AC input voltage applied to the rectifier. Please confirm that these terminals are configured properly (refer to the electrical schematic) for the AC voltage being applied.
- The final possibility is most likely that the rectifier AC input circuit breaker itself has failed and will require replacement.

F. RECTIFIER OUTPUT IS INTERMITTENT: Possible causes for erratic are:

- Broken or loose connections. Check all rectifier connections for loose or broken connections. Include the wiring connections to the **SENTRY** Controller.
- Check if built-in or field attached interrupters are in operation.

TROUBLESHOOTING SUMMARY:

As rectifier problems in automatic units can be more easily solved by having a good working knowledge of the application and the workings of the rectifier, review this manual to ensure recommended installation practices have been followed. If a problem cannot be solved, please contact your rectifier dealer or the factory for technical assistance.



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15360 - 116 Avenue, Edmonton, Alberta, Canada T5M 3Z6

Page 1 of 1

RECTIFIER DATA SHEET

MODEL No. : CIASFS 60-34 LMaOxQaVW SERIAL No. : 07R-0411 DATE : MAY 14, 2007
 CUSTOMER : FREEMAN INDUSTRIES INC. M.S.O. No. : 002650-1-1 P.O. #: 07-001
 AC VOLTS : 115 / 230 INPUT V.A. : 3,803 DC VOLTS : 60 TYPE : IR-FREE POTENTIAL
 AC AMPS : 33.1 / 16.5 PH. : 1 CYCLES : 60 DC AMPS : 34 CCTS. : SINGLE

QTY.	ITEM NUMBER	COMPONENT	COMPONENT DESCRIPTION
1	090-A-0230	ENCLOSURE	A-2, 8 GA. MARINE GRADE ALUMINUM, WHITE
1/1	092-A-0200/0205	FRAME (LEFT & RIGHT)	A-2, 12 GAUGE MILL-GALV. STEEL, WHITE
2	092-A-0210	TX. MOUNTING BRACKET	A-2, 12 GAUGE MILL-GALV. STEEL, WHITE
1	095-M-A200	INSTRUMENT PANEL	NEMA "XX", 1/4" x 13.25" x 16.25"
1	A-2 ADVANTAGE	AC INPUT CONN. STRIP, "TS1"	1/4" TERMINALS WITH BARRIER
1	031-B-035A/600V	AC CIRCUIT BREAKER, "CB1-A"	35.0 AMPERE, 600 VAC, 1-POLE
1	031-B-020A/600V	AC CIRCUIT BREAKER, "CB1-B"	20.0 AMPERE, 600 VAC, 1-POLE
1/1	008-A-1124/008-P-279-1	AC ARRESTOR/BRAKET, "AA1"	115/230 VAC, 1-PH. 3-WIRE / 16 GA. ALUM., BARE
1	T-060034-F16S25A	MAIN TRANSFORMER, "T1"	115/230VAC, 60 Hz, 1-PH., SCR, 25-STEPS
2	078-C-01000	AC SECONDARY TAP BAR, "TS2"	COPPER, NICKEL PLATED, 1/8" x 0.75" x 2.5"
4	054-K-0014P	KNOBS, TAP-BAR ADJUSTMENT	THUMB KNOB, 1/2-20 BRASS INSERT, BLACK
2	037-R-0050	TX. SECONDARY FUSE "F1"	50 AMPERE, 250 VOLT, TIME LAG
2	038-C-0020	AC SECONDARY FUSE CLIP	COPPER, NICKEL PLATED, 13/16" DIA x 3.00"
1	002-TB-175/1200V	SCR-DIODE MODULE, "BR1"	70 AMP, 1200 PIV, c/w FREE-WHEELING DIODE
1	066-P-0486	HEATSINK	CLEAR CHROMATE
1	007-G-0S20K130	BRIDGE AC VARISTOR, "MOV1"	130 VAC (RMS), 74 JOULES, 22.5 mm, 2-WIRE
2	009-M-1N4005	GATE STEERING DIODE	1.0 AMPERE, 600 VOLTS
4	022-C-R330	GATE DRIVE LIMIT RESISTOR	PARALLEL 330R0 OHMS, 2 WATT, AXIAL LEAD
1	046-S-8531K4	MODE SELECTOR SWITCH, "S2"	DPDT, SEALED, "AUTOMATIC - MANUAL"
0.33	052-N-323/12	SCR GATE TERM-BLOCK, "TS4"	4-TERMINAL, 25-AMP, 250VAC, DOUBLE ROW
1	061-P-2000	METER POWER SUPPLY, "PS1"	115 VAC, DUAL 5 VOLT SUPPLY, 750 mA
1	040-D-0020	DIGITAL VOLTMETER	3.5 DIGIT, ± 199.9 VOLTS, BRIGHT RED LED
1	040-D-0010	DIGITAL AMMETER	3.5 DIGIT, ± 199.9 AMPERES, BRIGHT RED LED
1	040-D-0020	DIGITAL POTENTIAL METER	3.5 DIGIT, ± 199.9 MILLIVOLTS, BRIGHT RED LED
1	061-M-0100-00	DIG. METER ADAPTER BOARD	3-METER, WITH 10-PIN CONNECTOR
1	043-B-SW50050	BLOCK SHUNT, "SHT"	50-AMPERE, 50mV, TYPE "SW" (1mV / AMP.)
1	046-S-8502K4	METER ON-OFF SWITCH, "S4"	4PDT, "METERS ON - OFF", SEALED
1	061-F-0200-02	SENTRY CONTROLLER, Rev. 2.0	IR-FREE POTENTIAL CONTROL, 115 VAC.
1	026-M-1010	POTENTIOMETER, "P1"	PANEL MOUNTED, MULTI-TURN, 10K.
1	047-K-01000	POTENTIOMETER KNOB	0.78" DIA, 1/4" SHAFT, BLACK
1	046-S-8501K5	POTENTIAL SET SWITCH, "S3"	DPDT, SEALED, "ACTUAL - SET POTENTIAL"
1	046-S-8531K4	REF-CELL SELECT SWITCH, "S1"	DPDT, SEALED, "REFERENCE 1 - REFERENCE 2"
1	052-D-141/03	POTENTIAL TERM-BLOCK, "TS3"	3-TERMINAL, 20 AMP, 300 VAC
1	052-N-323/10	REMOTE MONITOR TERMINALS, "TS5"	10-TERMINAL 25-AMP, 250VAC, DOUBLE ROW
1	008-D-1002	DC SURGE ARRESTOR, "DA1"	100 Vpeak, 2-TERMINAL
2	051-C-0030	DC OUTPUT LUG TERMINALS	#1/0-6 AWG, 1-HOLE, COPPER, NICKEL PLATED
1	APC0010-Rev.3.0	O&M MANUAL	8.5" x 11", INSIDE PROTECTIVE PACKET
1	CI1-F1H1B131-LMaOQaV1	ELECTRICAL SCHEMATIC	11" x 17", FOR INCLUSION WITH O&M MANUAL

NOTES:

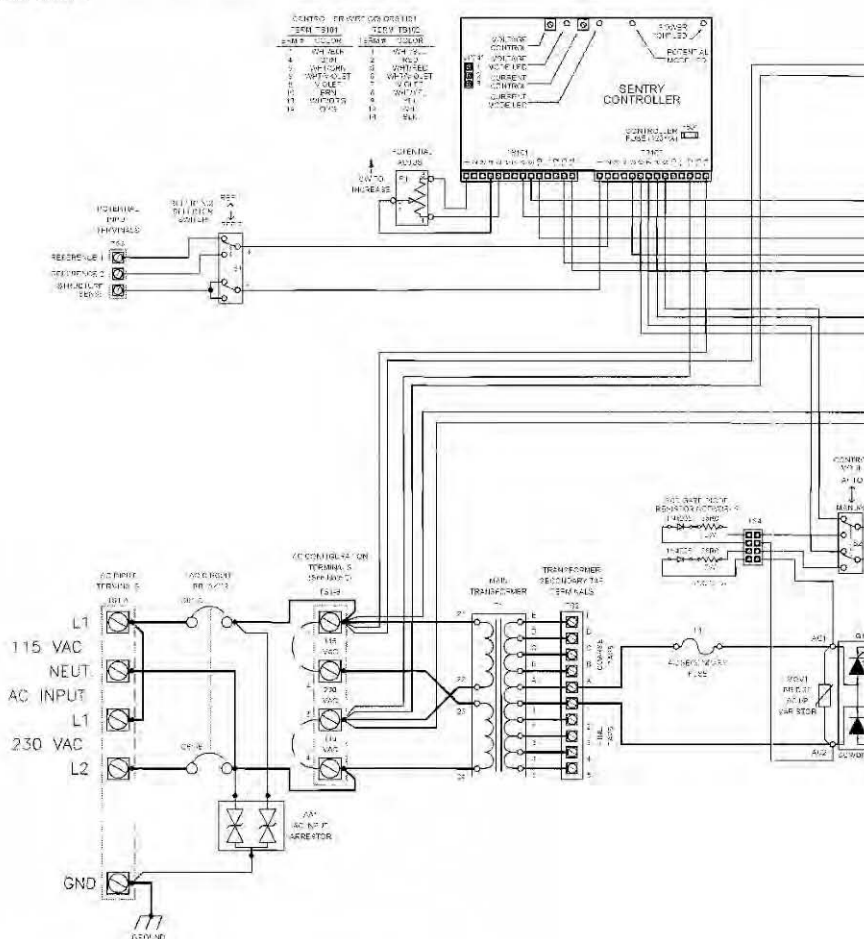
- OPTION "L": Rectifier equipped with additional Reference Electrode input & sealed selector switch.
- OPTION "M₂": Rectifier c/w sealed switches for: "Ref-Cell Select", "Auto-Manual" mode, Potential "Set-Actual", & Meter "On-Off".
- OPTION "O_x": Rectifier equipped with sealed "AUTOMATIC - MANUAL" mode switch.
- OPTION "Q_x": Rectifier equipped with a 25-Steps of Tap-Bar Adjustment on transformer.
- OPTION "V": Rectifier equipped with Terminal Strip for Remote Monitoring of Volts, Amperes, & IR-Free Potential.
- OPTION "W": Rectifier supplied with Marine Grade Aluminum enclosure, c/w S.S. latch.

AC PRIMARY: #10 TEW AC SECONDARY: #8 TEW DC OUTPUT: #10 TEW

Rev. 0

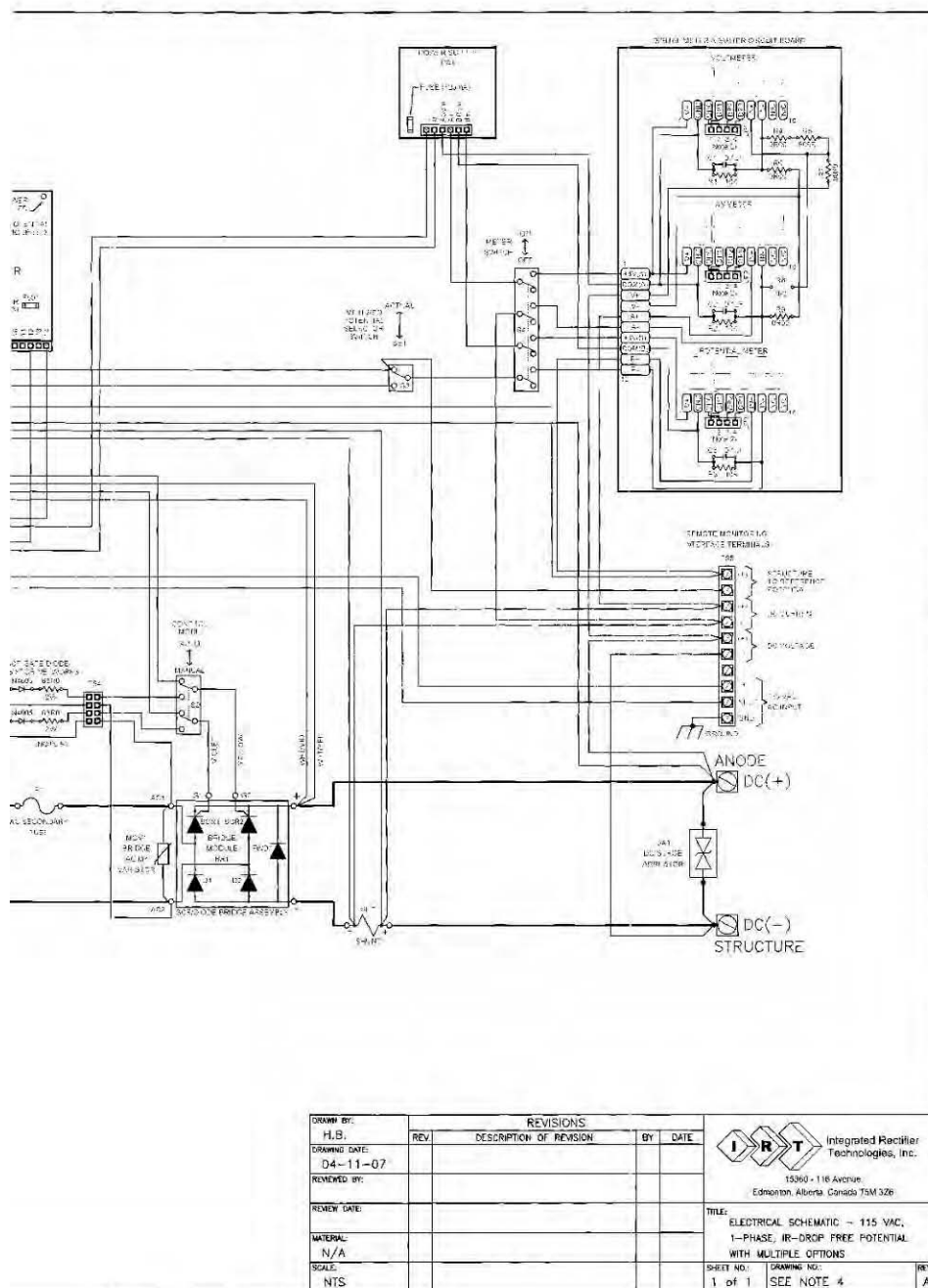
IMPORTANT NOTICE

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NOTES

- NOTES**
- 1) FOR COMPONENT DESCRIPTIONS, PART NUMBERS AND QUANTITIES, REVIEW THE RECTIFIER DATA SHEET
 - 2) CONFIGURE THE METER DISPLAYS AS FOLLOWS:
FOR ONE DECIMAL POINT, JUMPER 1-2
FOR TWO DECIMAL POINTS, JUMPER 2-3
FOR THREE DECIMAL POINTS, JUMPER 3-4
 - 3) AS THE BATTERY CONTROLLER IS POWER SENSITIVE, ENSURE THAT THE RECTIFIER TRANSFORMER AND SIGNAL CONDITIONING ASSEMBLY ARE WIRED AS PER THE SIGNAL MOUNT
 - 4) DRAWING NUMBER: CSE-HB131-1300000
 - 5) IF THE RECTIFIED OUTPUT VOLTAGE IS GREATLY HIGHER THAN 10VDC, PLEASE REFER TO THE RECTIFIER DATA SHEET FOR THE COMPONENT VALUE



Appendix C: DART RMU Hardware Specification

Dart for Rectifier - Hardware Specification 2007-07-30 -

DART for Rectifier - Hardware Specification -

1. Power Supply

- | | |
|-----------------------|--------------|
| 1.01. Input Voltage : | 9V to 36V DC |
| 1.02. Input Current : | 100mA at 12V |

2. Radio Specification

- | | |
|---------------------------|-------------------------------------|
| 2.01. Frequency : | 902-928 MHz ISM band |
| 2.02. Power : | 130dB link budget (250mW) |
| 2.03. Data Rate : | 152.34kbit/sec maximum RF data rate |
| 2.04. Antenna connector : | SMA |

3. Dimensions (Approximately)

- | | |
|----------------|-----------------------|
| 3.01. Length : | 2" (ca. 5 cm) |
| 3.02. Width : | 7" (ca. 17,5 cm) |
| 3.03. Height : | 6" (ca. 15 cm) |
| 3.04. Weight : | 16 ¼ oz (ca. 460 g) |

4. Terminal block (From left to right)

- | | |
|----------------|--------------------------------------------------|
| 4.01. Orange : | Rectifier voltage, positive |
| 4.02. Grey : | Rectifier voltage, negative |
| 4.03. Orange : | Rectifier amperage (shunt), positive |
| 4.04. Grey : | Rectifier amperage (shunt), negative |
| 4.05. Orange : | Structure potential, positive (Structure) |
| 4.06. Grey : | Structure potential, negative (Reference Cell) |
| 4.07. Blue : | Relay1, normally closed contact |
| 4.08. White : | Relay, common contact |
| 4.09. Blue : | Relay2, normally open contact |
| 4.10. Orange : | Power supply, positive |
| 4.11. Grey : | Power supply, negative |

Dart for Rectifier - Hardware Specification 2007-07-30 -

5. Electrical characteristics

- 5.11. Channel 1 input range : +/- 256.02 V (Depending on calibration)
- 5.12. Channel 1 impedance : > 200 k Ω
- 5.13. Channel 1 resolution : < 10mV
- 5.14. Channel 1 accuracy : < 1%

- 5.21. Channel 2 input range : +/- 156.25 mV
- 5.22. Channel 2 impedance : > 20 M Ω
- 5.23. Channel 2 resolution : < 5 μ V
- 5.24. Channel 2 accuracy : < 1%

- 5.31. Channel 3 input range : +/- 7189.56 mV (Depending on Calibration)
- 5.32. Channel 3 impedance : > 20 M Ω
- 5.33. Channel 3 resolution : < 0,2mV
- 5.34. Channel 3 accuracy : < 1%

- 5.41. Relay max. voltage : 24 V
- 5.42. Relay max. current : 50 mA

6. LED's (Determined by Software)

6.1. Data Logger Mode

- 6.1.1. LED A : Activated with full memory (End of measurements)
Deactivated with new settings (Initialisation)
- 6.1.2. LED B : Activated with first sample (Start of cycle)
Deactivated with last sample (End of cycle)
- 6.1.3. LED C : POWER LED (1 kHz)

6.2. Interrupter Mode :

- 6.2.1. LED A : State of relay 1
- 6.2.2. LED B : State of relay 2
- 6.2.3. LED C : POWER LED (1 kHz)

Dart for Rectifier - Hardware Specification 2007-07-30 -

7. Board Layout and Photo

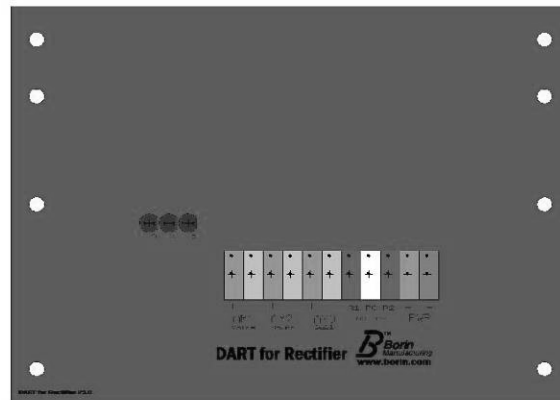


Fig. 1 : Dart for Rectifier, board layout

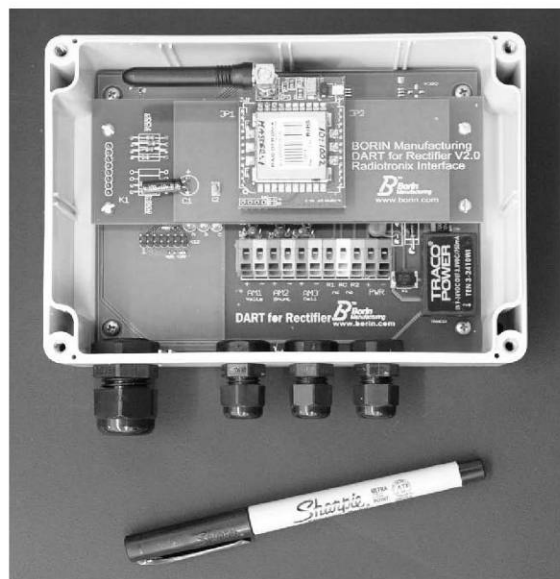


Fig 2 : Dart for Rectifier, photo

Dart for Rectifier - Hardware Specification 2007-07-30 -

8. Outline (inch) for mounting holes – not to scale

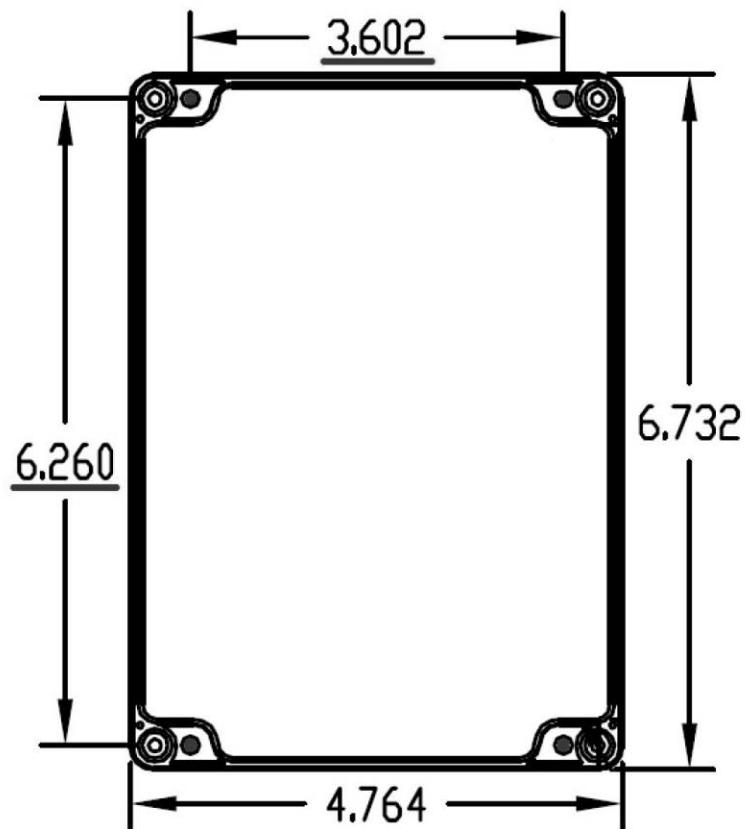
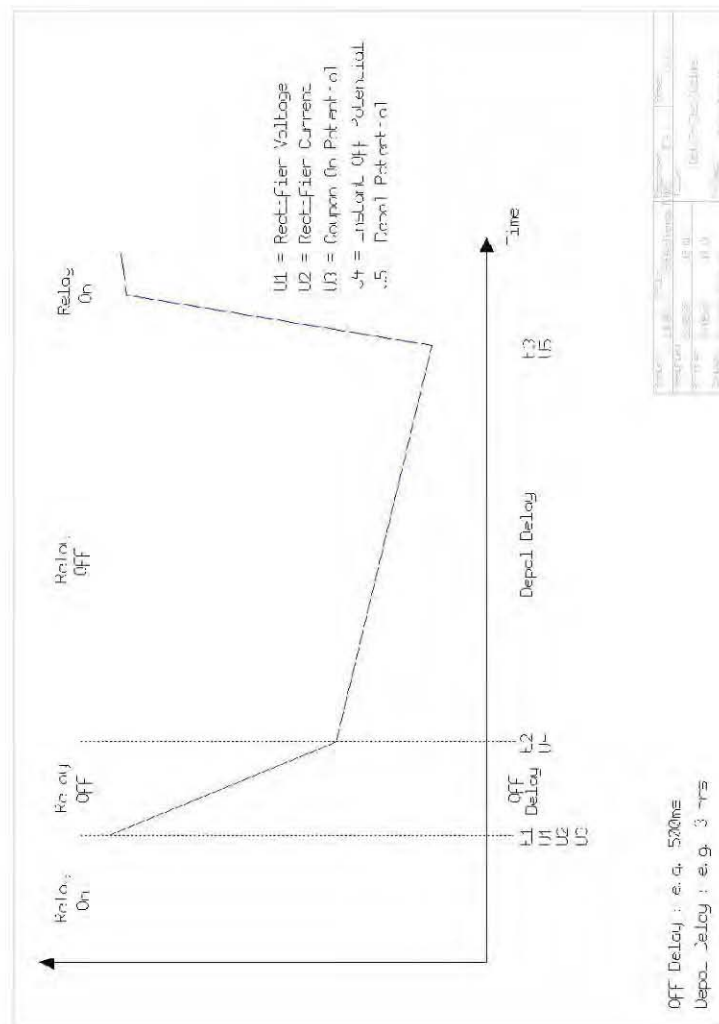


Fig 3 : Mounting holes

Dart for Rectifier - Hardware Specification 2007-07-30 -

9. Timing Parameters



Appendix D: Baseline Native Potential Surveys

Native potentials of gas lines before RMU installation, 24 March 2007

Proposed DART Site No.	Native Potential (-mV vs portable Cu-CuSO ₄)
1	-169
2	-399
3	-801
4	-135
5	-378
6	-555
7	-422
8	-517
9	Locked area
10	-361
11	-410
12	-381
13	-428
14	-643
15	Locked area
16	-3441
17	-556
18	-310
19	-401
20	-388
21	-411
22	-625
23	-327
24	-185
25	-347
26	-98 outside plastic conduit; and -77 inside conduit
27	-435
28	-146
29	-288
30	-317
31	-331

Proposed DART Site No.	Native Potential (-mV vs portable Cu-CuSO4)
32	-65 in wetted concrete in plastic conduit
33	-491
34	-602
35	-581
36	-249
37	-381
38	-206
39	-417
40	-1587
41	-260
42	-336
43	-956
44	-435
45	-236
46	-455
47	-564
48	-335
49	-376
50	-22
51	-502
52	-151
53	-178
54	-384
55	-379
56	-3
57	-406
58	-467
59	-434
60	-437
61	-411
62	-490
63	-420
64	-429
65	-333
66	-286
67	-384
68	-349
69	-412

Proposed DART Site No.	Native Potential (-mV vs portable Cu-CuSO4)
70	-344
71	-416
72	-401
73	-439
74	-9
75	-469
76	-411
77	-400
78	-479
79	-500
80	-441
81	-229
82	-404
83	-378
84	-1
85	-293
86	-275
87	-419
88	-395
89	-554
90	-429
91	-459
92	-381
93	-328
94	0
95	-433
96	-209
97	-183
98	-317
99	-473
100	-465
101	-316
102	-329
103	-458
104	-316
105	-340
106	-377
107	-311

Native potentials of gas lines, CP not energized, 19 October 2007

Test Station No.	Structure Potential (mV) vs Portable Cu/CuSO ₄ Ref Cell	Structure Potential (mV) vs DART Ref Cell (PR1)
1	-121	-182
2	-499	-485
3	-761	-774
4	-173	-162
5		
6	-343	-373
7	-348	-445
8	-457	-403
9		
10	-341	-330
11	-393	-380
12	-311	-292
13	-443	Structure and coupons all zero vs Borin reference cell
14	-205	-182
15		
16	-4527	-3933
17	-642	-668
18	-310	-277
19	-507	-434
20	-298	-354
21	-333	-285
22	-235	-252
23	-286	-308
24	-185	-161
25	-141	-71
26	-483	-456
27	-485	-441
28	-151	-148
29	-323	-288
30	-331	-284
31	-232	-205
32	-362	-379
33	-518	-486
34	-380	-279
35	-577	-538

Test Station No.	Structure Potential (mV) vs Portable Cu/CuSO4 Ref Cell	Structure Potential (mV) vs DART Ref Cell (PR1)
36	-236	-187
37	-409	-424
38	-263	-179
39		
40	-1349	-1268
41	-238	-237
42		
43	-765	-757
44	-398	-393
45	-254	-237
46	-289	-268
47	-393	-411
48	-247	-226
49	-190	-162
50	-222	-233
51	-289	-327
52		
53		
54		
55	-386	-352
56	-406	-387
57	-391	-367
58	-460	-487
59	-446	-431
60	-441	-416
61	-437	-412
62	-475	-435
63	-375	-375
64	-454	-386
65	-377	
66	-313	-310
67	-243	-271
68	-351	-377
69	-396	-370
70	-136	-132
71	-458	-408
72	-426	-418
73	-428	-402

Test Station No.	Structure Potential (mV) vs Portable Cu/CuSO4 Ref Cell	Structure Potential (mV) vs DART Ref Cell (PR1)
74	-327	-312
75		
76		
77		
78		
79		
80		
81		
82		
83		
84		
85		
86		
87		
88		
89	-500	-456
90	-439	-442
91	-297	-278
92	-256	-234
93	-390	-328
94	-513	-506
95	-299	-307
96	-231	-173
97	-263	-203
98		
99		
100		
101		
102		
103		
104		
105		

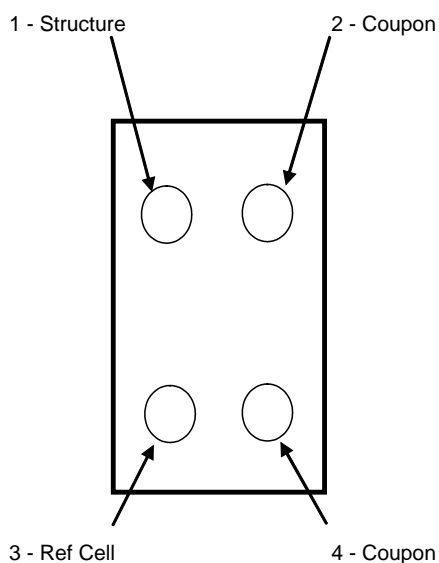
Notes

All 4 DART terminals -393 mV vs portable ref cell. On 10/19/07 retested by disconnecting all leads from DART unit and measuring them individually vs Borin ref cell; Structure lead -388 mV; coupon 1 lead -304 mV;

coupon 2 lead -303 mV. Borin ref cell lead -54 mV vs portable ref cell. Structure vs. portable ref cell, -443 mV. Reconnected all leads and reread. This time readings OK per preceding. Apparently whatever "short" existed appears to have cleared as a result of disconnecting the DART leads and reconnecting them.

Retested on 10/19/07; similar data obtained as on 10/16/07; did trouble-shooting and found DART wired backwards; i.e., #12 and #16 black leads reversed; yellow and orange leads reversed; rewired correctly and remeasured TS-65 (see below).

DART RMU Terminals



<u>TS-65 : Measured Potentials</u> <u>on 10/16/07</u>		
Terminal	vs. DART Ref Cell (mV)	vs. Portable Ref Cell (mV)
1	0	-377
2	1	-375
3	N/A	-21
4	-355	-375

Appendix E: Transformer/Rectifier Data

Washington Transformer/Rectifier

Model No. CCASFS60-34MaQa

S/N 07R-0408

AC Voltage 115/230; AC Amperage 33/16.5

DC Voltage 60; DC Amperage 34

NEMA 3R Enclosure 60 Hz/1-PH

Date	10/19/07	10/19/07	11/14/07	12/12/07
Time	2:35 p.m.	2:40 p.m.	9:00 a.m.	3:34 p.m.
T/R clock reading, hrs	1.7	1.7	621.7	1299.5
Tap setting, %	75	75	75	75
Current adjust setting, %	0	40	40	40
T/R mode	N/A	voltage	voltage	voltage
T/R Meter reading DC volts	0	49	48.5	48
T/R meter reading DC amps	0	1.2	1.7	2
Reading across +/- terminals, DC volts	0	49.48	49.11	48.85
Reading across 50 mV/40A shunt, mV	0	1.94	2.72	2.83
Computed current from shunt voltage drop, amps	0	1.552	2.176	2.264
Reading across 0.01-ohm anode shunt No. 1, mV	0	2.16	2.88	2.92
Reading across 0.01-ohm anode shunt No. 2, mV	0	3.35	4.28	4.26
Reading across 0.01-ohm anode shunt No. 3, mV	0	3.99	6.79	7.00
Reading across 0.01-ohm anode shunt No. 4, mV	0	5.98	7.76	8.24
Computed current from sum of voltage drops across anode shunts, amps	0	1.548	2.171	2.242
TS-7 Native potential, volts vs. Borin Cu/CuSO4 half cell	-0.454			
TS-7 Native potential, volts vs. portable Cu/CuSO4 half cell	-0.468			
TS-7 Polarized potential, volts vs. Borin Cu/CuSO4 half cell		-2.656	-3.159	-3.503
TS-7 Polarized potential, volts vs. portable Cu/CuSO4 half cell		-2.858	-3.142	

CEP#1 Transformer/Rectifier (outside Bldg 2288)

Model No. CCASFS60-34MaQa

S/N 07R-0407

AC Voltage 115/230; AC Amperage 33/16.5

DC Voltage 60; DC Amperage 34

NEMA 3R Enclosure 60 Hz/1-PH

Date	10/19/07	10/19/07	11/14/07	12/12/07	1/24/08
Time	3:15 p.m.	3:20 p.m.	9:35 a.m.	4:00 p.m.	1:25 p.m.
T/R clock reading, hrs	0.9	0.9	620.9	1298.3	2326.9
Tap setting, %	75	75	75	75	75
Current adjust setting, %	0	65	65	65	70
T/R mode	N/A	voltage	voltage	voltage	voltage
T/R Meter reading DC volts	0	56	56	57	56
T/R meter reading DC amps	0	17	16.5	16	16
Reading across +/- terminals, DC volts	0	56.5	56.1	56.5	56.1
Reading across 50 mV/40A shunt, mV	0	21.53	21.06	20.89	20.54
Computed current from shunt voltage drop, amps	0	17.224	16.848	16.712	16.432
Reading across 0.01-ohm anode shunt No. 1, mV	0	44.02	42.34	41.50	41.42
Reading across 0.01-ohm anode shunt No. 2, mV	0	34.14	31.49	30.37	27.31
Reading across 0.01-ohm anode shunt No. 3, mV	0	43.40	41.06	41.75	41.53
Reading across 0.01-ohm anode shunt No. 4, mV	0	50.00	53.30	53.00	53.7
Computed current from sum of voltage drops across anode shunts, amps	0	17.156	16.819	16.662	16.396
TS-16 Native potential, volts vs. Borin Cu/CuSO4 half cell	-3.941				
TS-16 Native potential, volts vs. portable Cu/CuSO4 half cell	-4.135				
TS-16 Polarized potential, volts vs. Borin Cu/CuSO4 half cell		-6.11	-5.47	-5.37	
TS-16 Polarized potential, volts vs. portable Cu/CuSO4 half cell		-6.67	-5.64		

Hill & Hardee Transformer/Rectifier

Model No. CCASF60-34MaQa

S/N 07R-?

AC Voltage 115/230; AC Amperage 33/16.5

DC Voltage 60; DC Amperage 34

NEMA 3R Enclosure 60 Hz/1-PH

Date	10/19/07	10/19/07	11/14/07	12/12/07	1/24/08
Time	3:45 p.m.	3:20 p.m.	10:25 a.m.	4:15 p.m.	1:35 p.m.
T/R clock reading, hrs	1.2	1.2	621.4	1298.3	2326.8
Tap setting, %	75	75	75	75	75
Current adjust setting, %	0	50	50	50	50
T/R mode	N/A	voltage	voltage	voltage	voltage
T/R Meter reading DC volts	0	59	59	58.5	57.5
T/R meter reading DC amps	0	9	9.5	9.5	9.5
Reading across +/- terminals, DC volts	0	58.5	58.2	57.4	56.8
Reading across 50 mV/40A shunt, mV	0	11.68	12.21	12.07	11.98
Computed current from shunt voltage drop, amps	0	9.344	9.768	9.656	9.584
Reading across 0.01-ohm anode shunt No. 1, mV	0	28.59	26.79	25.36	24.05
Reading across 0.01-ohm anode shunt No. 2, mV	0	17.81	18.95	19.63	20.91
Reading across 0.01-ohm anode shunt No. 3, mV	0	28.53	33.22	33.17	31.74
Reading across 0.01-ohm anode shunt No. 4, mV	0	17.79	18.44	18.08	18.85
Computed current from sum of voltage drops across anode shunts, amps	0	9.272	9.74	9.624	9.555
Native potential, volts vs. Borin Cu/CuSO4 half cell					
Native potential, volts vs. portable Cu/CuSO4 half cell	-0.454				
Polarized potential, volts vs. Borin Cu/CuSO4 half cell					
Polarized potential, volts vs. portable Cu/CuSO4 half cell		-9.36	-6.15		

Appendix F: DART RMU Data

Test Stations	Date	Structure Potential	Coupon ON Potential*	Coupon Instant OFF	Coupon 4 Hr Depolarized Potential	Potential More Neg. the -850 mV	Polar-ization = or > 100 mV	Polar-ization > 50 mV	Polar-ization > 20 mV	Polar-ization > 10 mV	Polar-ization > 0 mV	Coupon Current Pick Up	Polar-ization = or > 0	Original Natives	Valid Data
TS1 -Commissary	14-Jan-08	166.643	177.739	496.702	574.98	No	No	No	No	No	No	No	No		Yes
TS1 -Commissary	21-Jan-08	168.862	181.37	516.876	593.137	No	No	No	No	No	No	No	No		Yes
TS2 -5715 North	14-Jan-08	266.119	254.722	253.523	265.519	No	No	No	No	No	No	Yes	Yes		Yes
TS2 -5715 North	21-Jan-08	178.145	192.741	191.941	167.549	No	No	No	Yes	Yes	Yes	No	Yes		Yes
TS5	14-Jan-08	344.746	375.667	575.246	622.43	No	No	No	No	No	No	No	No		Yes
TS5	21-Jan-08	350.569	380.887	579.864	628.454	No	No	No	No	No	No	No	No		Yes
TS6 -1699	14-Jan-08	388.671	392.688	483.881	515.215	No	No	No	No	No	No	No	No		Yes
TS6 -1699	21-Jan-08	396.103	399.116	490.71	520.639	No	No	No	No	No	No	No	No		Yes
TS7 -Wash. & Essay.	14-Jan-08	4098.851	4060.352	1331.748	939.702	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes
TS7 - Wash. & Essay.	21-Jan-08	3751.553	3526.604	1429.71	1102.366	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes
TS8- Wash. & Marion	14-Jan-08	561.341	546.891	500.531	490.095	No	No	No	No	Yes	Yes	Yes	Yes		Yes
TS8- Wash. & Marion	21-Jan-08	569.971	557.328	482.268	471.631	No	No	No	No	Yes	Yes	Yes	Yes		Yes
TS10 - 2240	11-Jan-08	636.369	632.138	517.113	438.146	No	No	Yes	Yes	Yes	Yes	Yes	Yes		Yes
						No	No	No	No	No	No	Yes	Yes		No
TS11 - Across 2260	14-Jan-08	818.99	801.134	598.091	507.003	No	No	Yes	Yes	Yes	Yes	Yes	Yes		Yes
TS11 - Across 2260	21-Jan-08	833.636	819.993	612.938	518.239	No	No	Yes	Yes	Yes	Yes	Yes	Yes		Yes
TS12 -2260	14-Jan-08	624.678	594.768	592.342	580.015	No	No	No	No	Yes	Yes	Yes	Yes		Yes
TS12 -2260	21-Jan-08	589.715	562.028	560.815	561.422	No	No	No	No	No	No	Yes	Yes		Yes
TS13 -3260	14-Jan-08	672.565	674.741	635.981	628.07	No	No	No	No	No	Yes	No	Yes		Yes
TS13 -3260	21-Jan-08	677.114	675.729	634.794	623.126	No	No	No	No	Yes	Yes	Yes	Yes		Yes
TS14 -2410	14-Jan-08	366.169	391.922	608.606	645.223	No	No	No	No	No	No	No	No		Yes
TS14 -2410	21-Jan-08	403.188	448.457	527.123	550.863	No	No	No	No	No	No	No	No		Yes
TS16 -2288	14-Jan-08	5024.995	3696.737	1015.666	679.526	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes
TS16 -2288	21-Jan-08	5243.184	3955.183	1019.692	710.524	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes
TS17 -4333	14-Jan-08	1099.567	1079.282	769.438	594.629	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes
TS17 -4333	21-Jan-08	1086.839	1060.588	863.505	736.425	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes
TS18 -1895	14-Jan-08	293.871	293.871	281.618	281.819	No	No	No	No	No	No	Yes	Yes		Yes
TS18 -1895	21-Jan-08	306.526	306.124	294.273	295.277	No	No	No	No	No	No	Yes	Yes		Yes

Test Stations	Date	Structure Potential	Coupon ON Potential*	Coupon Instant OFF	Coupon 4 Hr Depolarized Potential	Potential More Neg. the -850 mV	Polar-ization = or > 100 mV	Polar-ization > 50 mV	Polar-ization > 20 mV	Polar-ization > 10 mV	Polar-ization > 0 mV	Coupon Current Pick Up	Polar-ization = or > 0	Original Natives	Valid Data
TS19 -Wash. & Hall	14-Jan-08	1112.495	1108.663	527.003	406.395	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes
TS19 -Wash. & Hallt	21-Jan-08	1125.201	1106.242	535.877	398.731	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes
TS20 -4710	14-Jan-08	675.53	689.954	748.853	761.274	No	No	No	No	No	No	No	No		Yes
TS20 -4710	21-Jan-08	651.69	667.116	747.851	764.078	No	No	No	No	No	No	No	No		Yes
TS21 -2179	14-Jan-08	484.355	498.671	698.1	747.503	No	No	No	No	No	No	No	No		Yes
TS21 -2179	21-Jan-08	503.309	515.811	696.89	749.923	No	No	No	No	No	No	No	No		Yes
TS22 -2078	14-Jan-08	466.889	465.685	379.611	264.443	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes
TS22 -2078	21-Jan-08	482.94	485.147	401.48	258.023	No	Yes	Yes	Yes	Yes	Yes	No	Yes		Yes
						No	No	No	No	No	No	Yes	Yes		No
TS24 -2139 South	14-Jan-08	221.633	226.857	465.772	512.59	No	No	No	No	No	No	No	No		Yes
TS24 -2139 South	21-Jan-08	235.297	240.32	460.346	505.959	No	No	No	No	No	No	No	No		Yes
TS25 -2139 Back	14-Jan-08	299.356	554.452	580.405	586.44	No	No	No	No	No	No	No	No		Yes
TS25 -2139 Back	21-Jan-08	425.295	606.96	626.475	635.93	No	No	No	No	No	No	No	No	334	Yes
TS26 -2159	14-Jan-08	506.749	544.6	544.6	545.002	No	No	No	No	No	No	No	Yes		Yes
TS26 -2159	21-Jan-08	529.097	549.834	549.834	549.23	No	No	No	No	No	Yes	No	Yes		Yes
TS27 -2280	14-Jan-08	523.299	522.696	348.665	245.773	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes
TS27 -2280	21-Jan-08	525.912	526.313	429.049	387.651	No	No	No	Yes	Yes	Yes	Yes	Yes		Yes
TS28 -3210	14-Jan-08	372.24	374.655	530.593	558.36	No	No	No	No	No	No	No	No		Yes
TS28 -3210	21-Jan-08	386.526	388.136	525.563	552.525	No	No	No	No	No	No	No	No		Yes
TS29 -3255	14-Jan-08	370.766	376.979	536.709	560.358	No	No	No	No	No	No	No	No		Yes
TS29 -3255	21-Jan-08	377.38	382.991	534.705	560.558	No	No	No	No	No	No	No	No		Yes
TS30 - 3250	14-Jan-08	311.537	320.977	439.486	476.646	No	No	No	No	No	No	No	No		Yes
TS30 - 3250	21-Jan-08	316.96	327.003	449.127	488.095	No	No	No	No	No	No	No	No		Yes
TS31 -3280 North	14-Jan-08	227.371	259.881	523.978	551.07	No	No	No	No	No	No	No	No		Yes
TS31 -3280 North	21-Jan-08	209.31	212.922	275.133	410.192	No	No	No	No	No	No	No	No		Yes
TS32 -4210	14-Jan-08	343.783	638.857	645.097	645.701	No	No	No	No	No	No	No	No	0.05	Yes
TS32 -4210	21-Jan-08	390.681	638.455	641.474	642.279	No	No	No	No	No	No	No	No		Yes
TS33 -2420	11-Jan-08	484.302	484.705	436.134	425.654	No	No	No	No	Yes	Yes	Yes	Yes		Yes

Test Stations	Date	Structure Potential	Coupon ON Potential*	Coupon Instant OFF	Coupon 4 Hr Depolarized Potential	Potential More Neg. the -850 mV	Polar-ization = or > 100 mV	Polar-ization > 50 mV	Polar-ization > 20 mV	Polar-ization > 10 mV	Polar-ization > 0 mV	Coupon Current Pick Up	Polar-ization = or > 0	Original Natives	Valid Data
						No	No	No	No	No	No	Yes	Yes		No
TS34 -4250	14-Jan-08	739.773	723.909	724.11	723.106	No	No	No	No	No	Yes	Yes	Yes		Yes
TS34 -4250	21-Jan-08	736.158	724.913	724.913	723.909	No	No	No	No	No	Yes	Yes	Yes		Yes
TS35 -4169	14-Jan-08	552.899	553.502	523.768	512.517	No	No	No	No	Yes	Yes	Yes	Yes		Yes
TS35 -4169	21-Jan-08	553.703	553.904	522.763	524.772	No	No	No	No	No	No	Yes	Yes		Yes
TS36 -4270	11-Jan-08	366.846	674.845	696.389	703.969	No	No	No	No	No	No	No	No	38	Yes
						No	No	No	No	No	No	Yes	Yes		No
TS37 -4310	14-Jan-08	7.988	64.303	328.708	384.624	No	No	No	No	No	No	No	No		Yes
TS37 -4310	21-Jan-08	-119.82	-55.117	328.908	396.407	No	No	No	No	No	No	No	No		Yes
TS38 -4330	14-Jan-08	234.055	235.064	426.748	452.373	No	No	No	No	No	No	No	No		Yes
TS38 -4330	21-Jan-08	271.181	270.979	411.615	435.222	No	No	No	No	No	No	Yes	No		Yes
TS39 -4323	14-Jan-08	1329.034	1272.458	604.742	358.847	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes
TS39 -4323	21-Jan-08	1345.427	1289.051	619.536	360.446	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes
TS40 -Shopette	14-Jan-08	1384.291	1226.944	708.06	445.015	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes
TS40 -Shopette	21-Jan-08	1467.769	1354.863	864.005	632.99	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes
TS41 -5330	14-Jan-08	246.465	255.074	401.632	465.501	No	No	No	No	No	No	No	No		Yes
TS41 -5330	21-Jan-08	247.466	254.874	396.827	460.296	No	No	No	No	No	No	No	No		Yes
TS42 -2275	11-Jan-08	360.709	367.595	368	369.013	No	No	No	No	No	No	No	Yes		Yes
						No	No	No	No	No	No	Yes	Yes		No
TS43 -Mosbey & Forr.	14-Jan-08	819.62	800.105	594.898	547.62	No	No	No	Yes	Yes	Yes	Yes	Yes		Yes
TS43 -Mosbey & Forr.	21-Jan-08	820.224	808.354	608.378	555.668	No	No	Yes	Yes	Yes	Yes	Yes	Yes		Yes
TS44 -13200	11-Jan-08	478.341	610.228	617.488	619.101	No	No	No	No	No	No	No	No	199	Yes
						No	No	No	No	No	No	Yes	Yes		No
TS45 -13000	14-Jan-08	219.431	229.786	408.597	443.443	No	No	No	No	No	No	No	No		Yes
TS45 -13000	21-Jan-08	214.254	222.219	346.471	371.958	No	No	No	No	No	No	No	No		Yes
TS46 -TR12625	14-Jan-08	296.737	335.929	599.474	649.663	No	No	No	No	No	No	No	No		Yes
TS46 -TR12625	21-Jan-08	312.534	351.126	601.873	655.462	No	No	No	No	No	No	No	No		Yes
TS47 -TR12656	14-Jan-08	410.381	411.991	409.173	406.959	No	No	No	No	No	Yes	No	Yes		Yes

[illegible]

[illegible]

Test Stations	Date	Structure Potential	Coupon ON Potential*	Coupon Instant OFF	Coupon 4 Hr Depolarized Potential	Potential More Neg. the -850 mV	Polar-ization = or > 100 mV	Polar-ization > 50 mV	Polar-ization > 20 mV	Polar-ization > 10 mV	Polar-ization > 0 mV	Coupon Current Pick Up	Polar-ization = or > 0	Original Natives	Valid Data
TS78 -5421 North	14-Jan-08	395.99	386.405	384.808	385.606	No	No	No	No	No	No	Yes	Yes		Yes
TS78 -5421 North	21-Jan-08	381.013	381.413	387.204	388.602	No	No	No	No	No	No	Yes	No		Yes
TS79 -5502	14-Jan-08	704.003	430.578	661.523	706.795	No	No	No	No	No	No	Yes	No		Yes
TS79 -5502	21-Jan-08	706.396	432.373	661.922	708.789	No	No	No	No	No	No	Yes	No		Yes
TS80 -5501 North	14-Jan-08	408.528	428.894	581.739	607.953	No	No	No	No	No	No	No	No		Yes
TS80 -5501 North	21-Jan-08	402.68	418.207	575.488	605.936	No	No	No	No	No	No	No	No		Yes
TS82 -5505	14-Jan-08	278.618	358.797	608.551	642.627	No	No	No	No	No	No	No	No		Yes
TS82 -5505	21-Jan-08	298.062	359.398	628.997	667.081	No	No	No	No	No	No	No	No		Yes
TS83 -5472 South	14-Jan-08	354.47	438.639	372.063	353.87	No	No	No	No	Yes	Yes	No	Yes		Yes
TS83 -5472 South	21-Jan-08	369.664	437.839	383.859	368.065	No	No	No	No	Yes	Yes	No	Yes		Yes
TS86 -4394	11-Jan-08	169.488	176.099	445.558	497.647	No	No	No	No	No	No	Yes	Yes		No
						No	No	No	No	No	No	Yes	Yes		No
TS89 -4710	14-Jan-08	368.769	365.755	365.755	365.956	No	No	No	No	No	No	Yes	Yes		Yes
TS89 -4710	21-Jan-08	376.406	372.788	372.788	371.783	No	No	No	No	No	Yes	Yes	Yes		Yes
TS90 -4442	14-Jan-08	468.928	466.128	410.312	390.307	No	No	No	Yes	Yes	Yes	Yes	Yes		Yes
TS90 -4442	21-Jan-08	471.929	469.728	400.91	371.301	No	No	No	Yes	Yes	Yes	Yes	Yes		Yes
TS91 -4405 South	14-Jan-08	410.033	421.927	466.276	476.356	No	No	No	No	No	No	No	No		Yes
TS91 -4405 South	21-Jan-08	416.081	419.306	463.656	472.123	No	No	No	No	No	No	No	No		Yes
TS92 -4406	14-Jan-08	221.49	209.864	209.864	214.274	No	No	No	No	No	No	Yes	Yes		Yes
TS92 -4406	21-Jan-08	208.261	199.441	199.441	198.84	No	No	No	No	No	Yes	Yes	Yes		Yes
TS93 -Post Office	14-Jan-08	393.148	-1.806	-2.006	-2.006	No	No	No	No	No	No	Yes	Yes		Yes
TS93 -Post Office	21-Jan-08	399.771	-3.411	-3.813	-3.211	No	No	No	No	No	No	Yes	Yes		Yes
TS94 -3499	14-Jan-08	415.678	420.285	420.285	419.484	No	No	No	No	No	Yes	No	Yes		Yes
TS94 -3499	21-Jan-08	423.891	425.294	425.294	424.893	No	No	No	No	No	Yes	No	Yes		Yes
TS95 -2310	14-Jan-08	430.293	434.516	442.157	442.559	No	No	No	No	No	No	No	No		Yes
TS95 -2310	21-Jan-08	432.505	432.304	421.245	414.208	No	No	No	No	No	Yes	Yes	Yes		Yes
TS96 -Palmento	14-Jan-08	170.246	170.448	197.712	203.366	No	No	No	No	No	No	Yes	No		Yes

Test Stations	Date	Structure Potential	Coupon ON Potential*	Coupon Instant OFF	Coupon 4 Hr Depolarized Potential	Potential More Neg. the -850 mV	Polar-ization = or > 100 mV	Polar-ization > 50 mV	Polar-ization > 20 mV	Polar-ization > 10 mV	Polar-ization > 0 mV	Coupon Current Pick Up	Polar-ization = or > 0	Original Natives	Valid Data
TS96 -Palmento	21-Jan-08	177.516	177.516	195.086	187.008	No	No	No	No	No	Yes	Yes	No		Yes
TS97- 9810 Back.	14-Jan-08	181.285	193.156	491.542	527.558	No	No	No	No	No	No	No	No		Yes
TS97- 9810 Back.	21-Jan-08	193.558	202.009	489.329	519.711	No	No	No	No	No	No	No	No		Yes
TS98 -TR10773	14-Jan-08	289.349	290.356	214.997	175.503	No	No	No	Yes	Yes	Yes	No	Yes		Yes
TS98 -TR10773	21-Jan-08	289.55	285.117	205.929	163.212	No	No	No	Yes	Yes	Yes	Yes	Yes		Yes
TS99 -TR10775	14-Jan-08	399.889	407.101	479.426	495.053	No	No	No	No	No	No	No	No		Yes
TS99 -TR10775	21-Jan-08	405.899	400.69	470.41	487.64	No	No	No	No	No	No	Yes	No		Yes
TS100 -TR10774	14-Jan-08	402.275	396.413	304.637	237.524	No	No	Yes	Yes	Yes	Yes	Yes	Yes		Yes
TS100 -TR10774	21-Jan-08	386.103	377.411	297.966	225.597	No	No	Yes	Yes	Yes	Yes	Yes	Yes		Yes
TS101 -TR10788	14-Jan-08	288.559	285.337	220.296	176.8	No	No	No	Yes	Yes	Yes	Yes	Yes		Yes
TS101 -TR10788	21-Jan-08	272.248	265.2	202.172	156.059	No	No	No	Yes	Yes	Yes	Yes	Yes		Yes
TS102 -TR10777	14-Jan-08	-0.201	-0.201	-0.201	-0.201	No	No	No	No	No	No	Yes	Yes		No
TS102 -TR10777	21-Jan-08	-1.008	-0.604	-0.806	-0.806	No	No	No	No	No	No	Yes	Yes		No
TS104 -TR10778	14-Jan-08	285.193	303.644	499.79	528.47	No	No	No	No	No	No	No	No		Yes
TS104 -TR10778	21-Jan-08	272.959	279.778	474.52	498.988	No	No	No	No	No	No	No	No		Yes
TS105 -TR10779	14-Jan-08	333.413	336.64	344.91	351.97	No	No	No	No	No	No	No	No		Yes
TS105 -TR10779	21-Jan-08	328.976	333.413	385.452	411.27	No	No	No	No	No	No	No	No		Yes
TS106 -TR10782	14-Jan-08	350.983	363.982	502.775	519.175	No	No	No	No	No	No	No	No		Yes
TS106 -TR10782	21-Jan-08	349.783	349.183	457.977	470.777	No	No	No	No	No	No	Yes	No		Yes
TS107 -TR10783	14-Jan-08	291.11	7.76	8.357	10.944	No	No	No	No	No	No	Yes	Yes		Yes
TS107 -TR10783	21-Jan-08	294.692	4.178	4.775	7.362	No	No	No	No	No	No	Yes	Yes		Yes

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				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER Corrosion Prevention and Control	
6. AUTHOR(S) L.D. Stephenson, Ashok Kumar, James B. Bushman, and Bopinder Phull				5d. PROJECT NUMBER CPC FAR-20	
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13. SUPPLEMENTARY NOTES Additional Task Number is MIPR6HMBHDE097					
14. ABSTRACT This project demonstrated and implemented emerging corrosion protection technologies for utilities at Fort Jackson, SC. These consisted of three deep anode impressed current cathodic protection (ICCP) systems, 100 drive-by- type remote monitoring units (RMU) for monitoring the cathodic protection on the buried gas lines, and a new cathodic protection system in the elevated water storage tank, providing complete and uniform protection in the tank interior below the water line. The CP system in the water storage tank is also equipped with remote monitoring capability. The remote monitoring units have reduced the amount of time that it takes a trained technician to collect the data from about a week to only about 3 hours. The CP data collected from the drive by RMUs are collected and stored on a laptop computer for use in different analysis, including transfer into an Excel spreadsheet where it is automatically analyzed on a pass/fail basis.					
15. SUBJECT TERMS Fort Jackson, SC; cathodic protection (CP); natural gas distribution systems; water storage tanks; remote monitoring systems; corrosion control					
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